RESULTS AND DISCUSSION

Data Collection (7 factors)

The data collection consists of 7 factors, which were collected from several sources in GIS data form such as geology map (rock type and lineament), land form data (slope and elevation), surface drainage data, soil characteristic data, land use map, rainfall intensity data and engineering soil properties. These are illustrated in Fig 8-Fig 16 and the summation of the each factor is area shown in Table 19.

Table 19 Plan area of 7 factors

Factors	pixel	Area (km^2)	%
Rock type			
Granite rock	322,484	201.55	36.71
Shale/Mudstone	116,916	73.07	13.31
Sandstone/Siltstone	0	0.00	0.00
Quartzite, Sandstone and Siltstone	0	0.00	0.00
Limestone/Dolomite	0	0.00	0.00
Colluvial	439,017	274.39	49.98
Sum	878,417	549.01	100.00
Lineament zone			
Sum	12,459	7.79	100.00
Slope			
0	310,365	193.98	35.33
0 - 15%	580,857	363.04	66.13
15 - 30%	111,240	69.53	12.66
30 - 50%	131,575	82.23	14.98
50 - 70%	46,596	29.12	5.30
> 70%	8,149	5.09	0.93
Sum	878,417	549.01	100.00
Elevation			
0	46,195	28.87	5.26
0 - 100	686,455	429.03	78.15
100 - 200	105,822	66.14	12.05
200 - 300	53,434	33.40	6.08
300 - 400	24,564	15.35	2.80
> 400	8,142	5.09	0.93
Sum	878,417	549.01	100.00

Table 19 Plan area of 7 factors (Continued)

Factors	pixel	Area (km^2)	%
Surface drainage			
Sum	33,477	20.92	100.00
Soil characteristics			
Gravel loam/Gravelly sand	1,894	1.18	0.22
Sand	20,439	12.77	2.33
Sandy loam	288,217	180.14	32.81
Clayey loam/loam	424,755	265.47	48.35
Clay, Mud	143,112	89.45	16.29
Sum	878,417	549.01	100.00
Land use			
Agriculture area	514,594	321.62	58.58
Urban and build-up area	192,923	120.58	21.96
Other deforestation	1,881	1.18	0.21
Forest area	169,019	105.64	19.24
Sum	878,417	549.01	100.00
Engineering soil properties			
Residual soil from Sandstone/Siltstone	0	0.00	0.00
Residual soil from Granite rock	322,484	201.55	36.71
Residual soil from Shale/Mudstone	116,916	73.07	13.31
Residual soil from Quartzite, Sandstone and Siltstone	0	0.00	0.00
Residual soil from Limestone/Dolomite	0	0.00	0.00
Colluvial	439,017	274.39	49.98
Sum	878,417	549.01	100.00
Rainfall cumulative intensity 3 days			
A. >203 mm.	0	0.00	0.00
B. 161-203 mm.	9,001	5.63	1.02
C. 119-161 mm.	822,385	513.99	93.62
D. 77-119 mm.	46,831	29.27	5.33
E. 35-76 mm.	0	0.00	0.00
Other	200	0.13	0.02
Sum	878,417	549.01	100.00

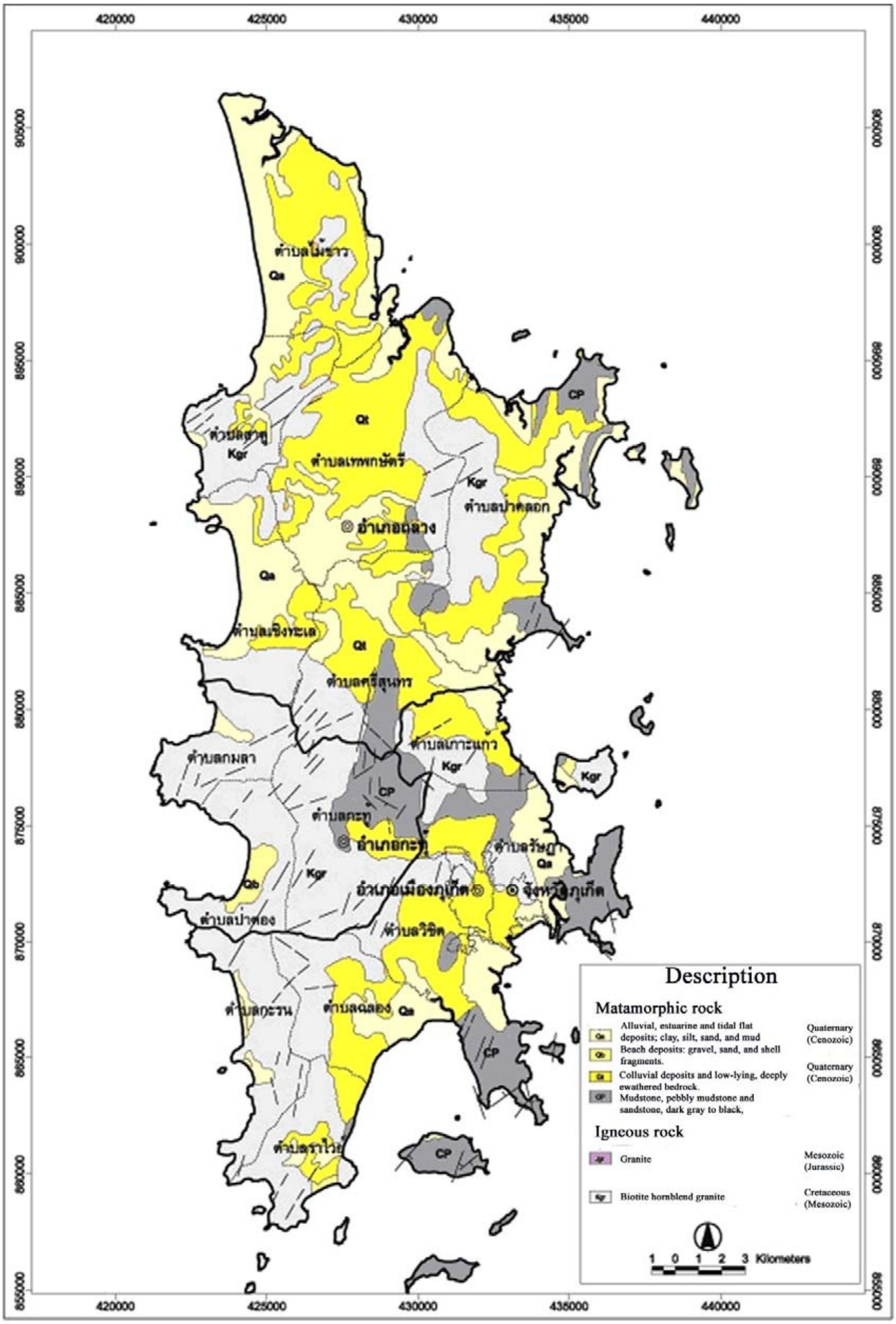


Figure 8 Geology (Rock type)
Source: Department of Mineral Resource (2006)

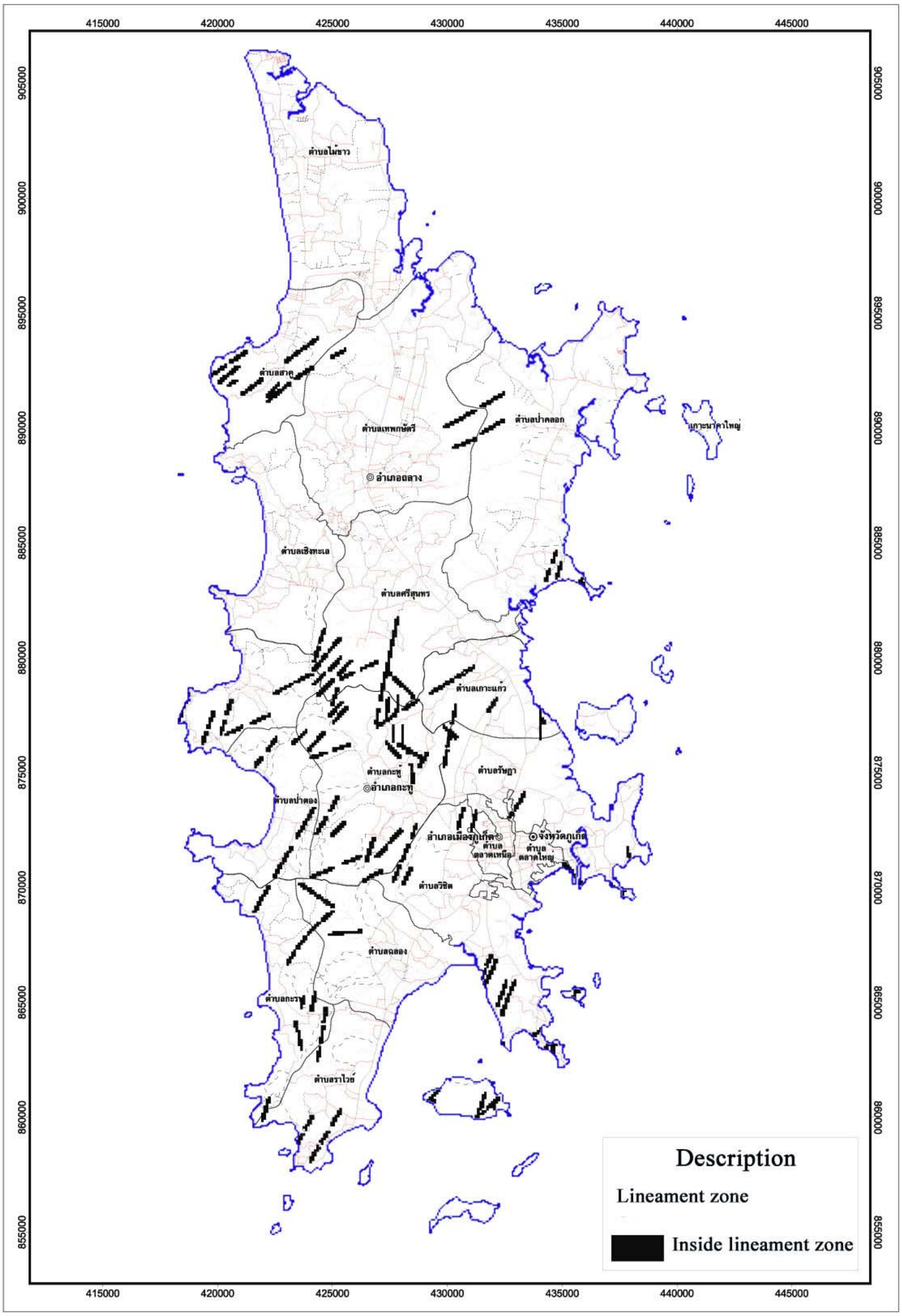


Figure 9 Geology (Lineament zone)
Source: Department of Mineral Resource (2006)

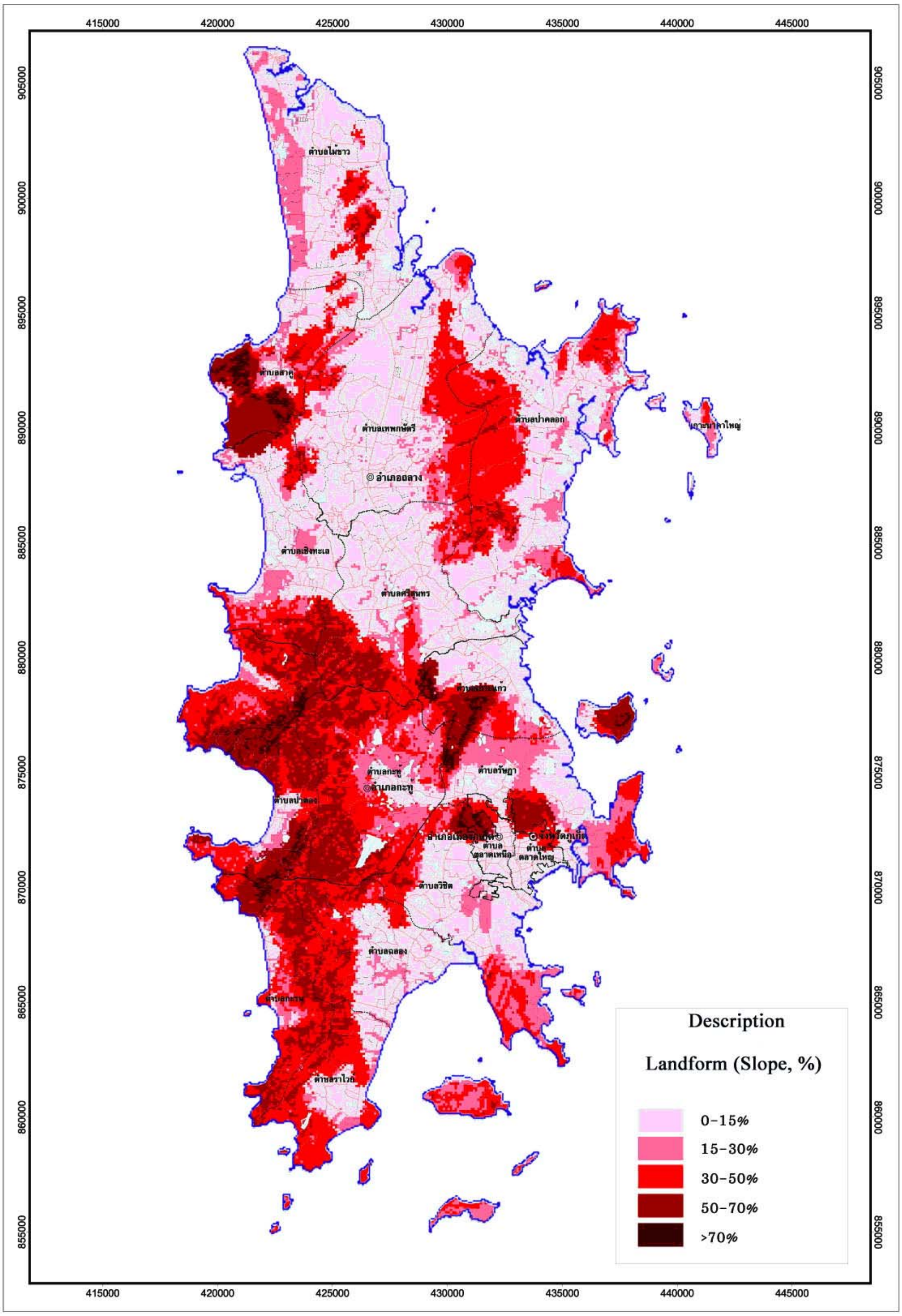


Figure 10 Landform (Slope)
Primary data: Royal Thai Survey Department (2006)

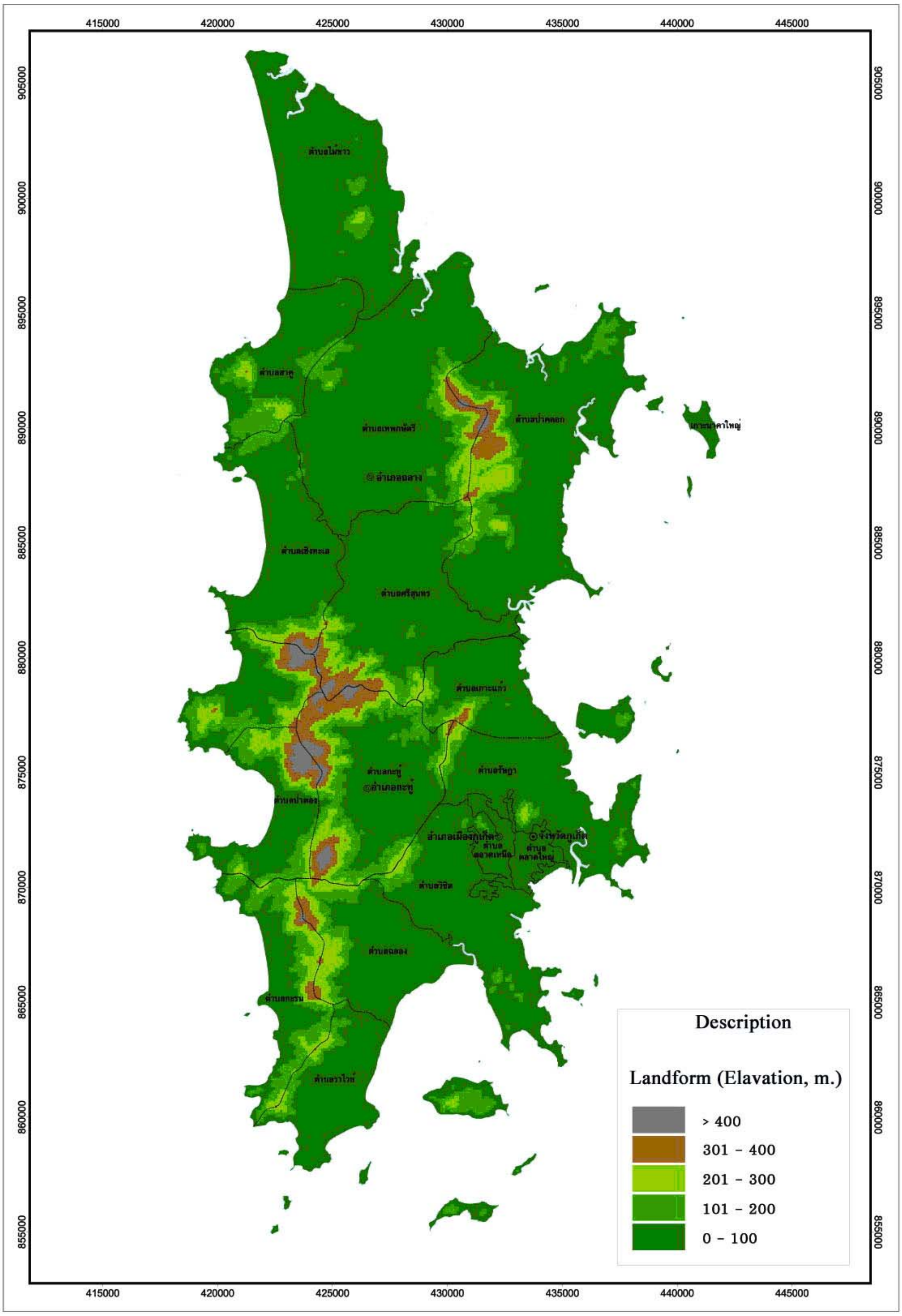


Figure 11 Landform (Elevation)
Primary data: Royal Thai Survey Department (2006)

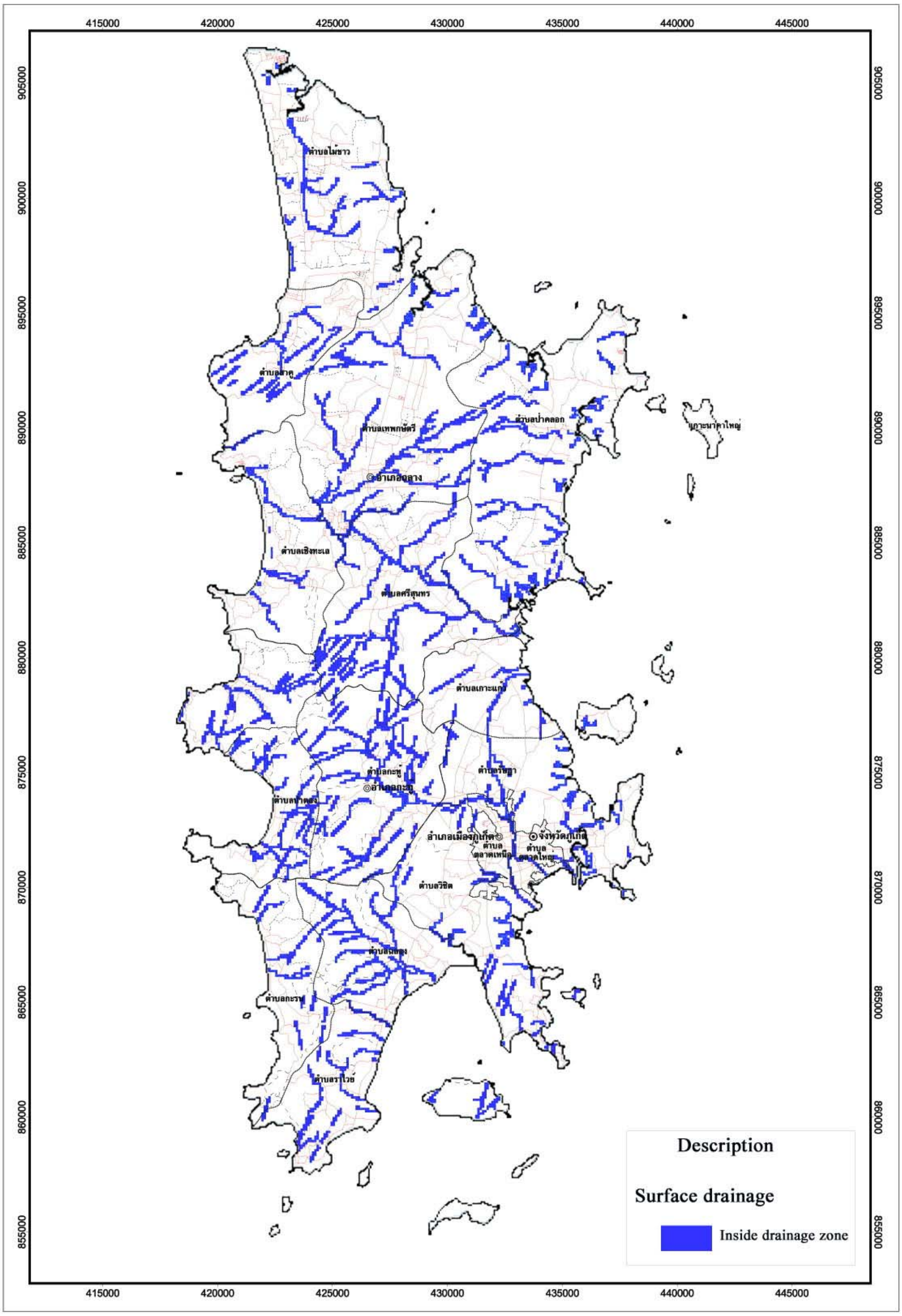


Figure 12 Surface drainage
Primary data: Royal Thai Survey Department (2006)

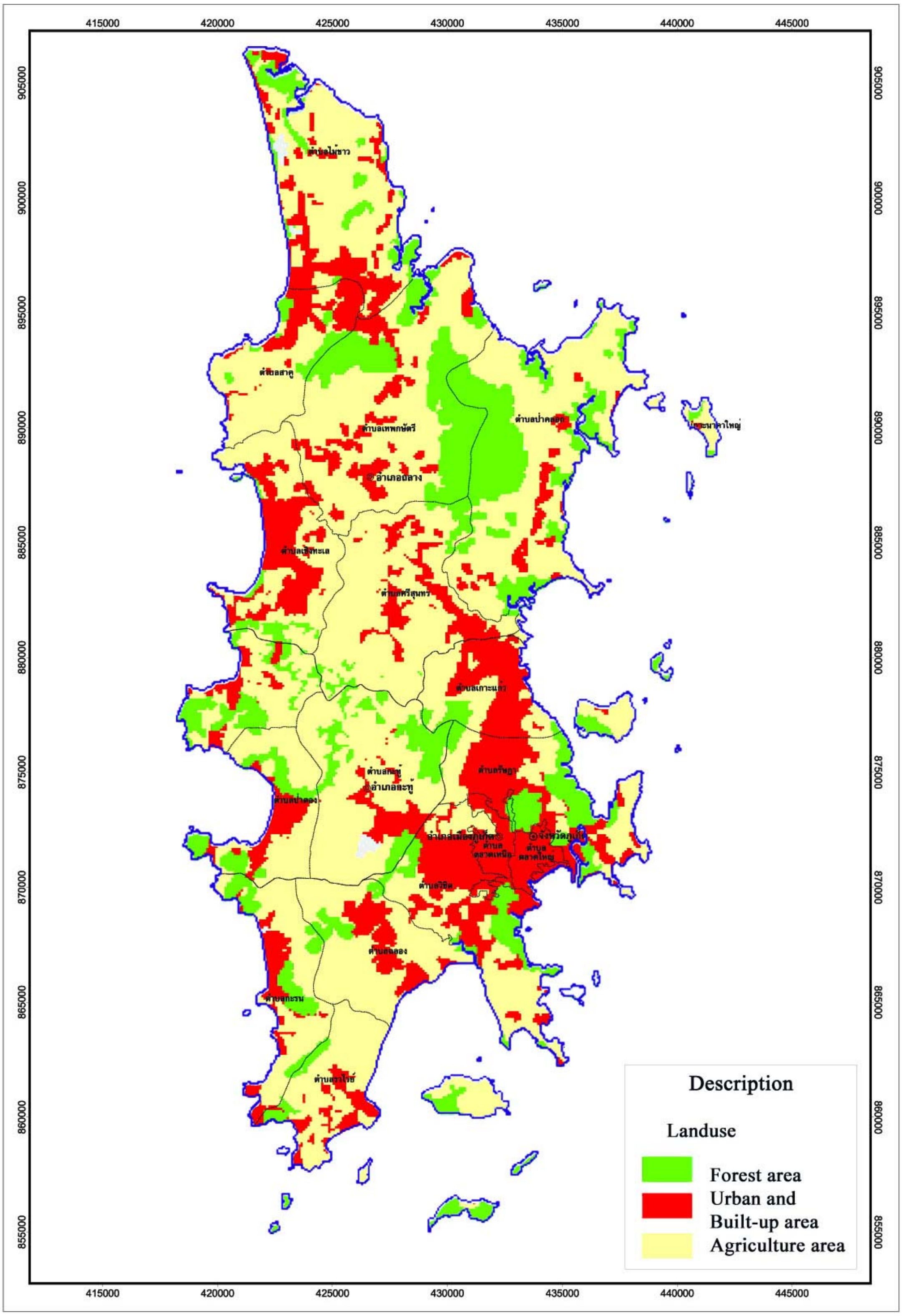


Figure 13 Land use and land cover
Primary data: Department of Land Development (2006)

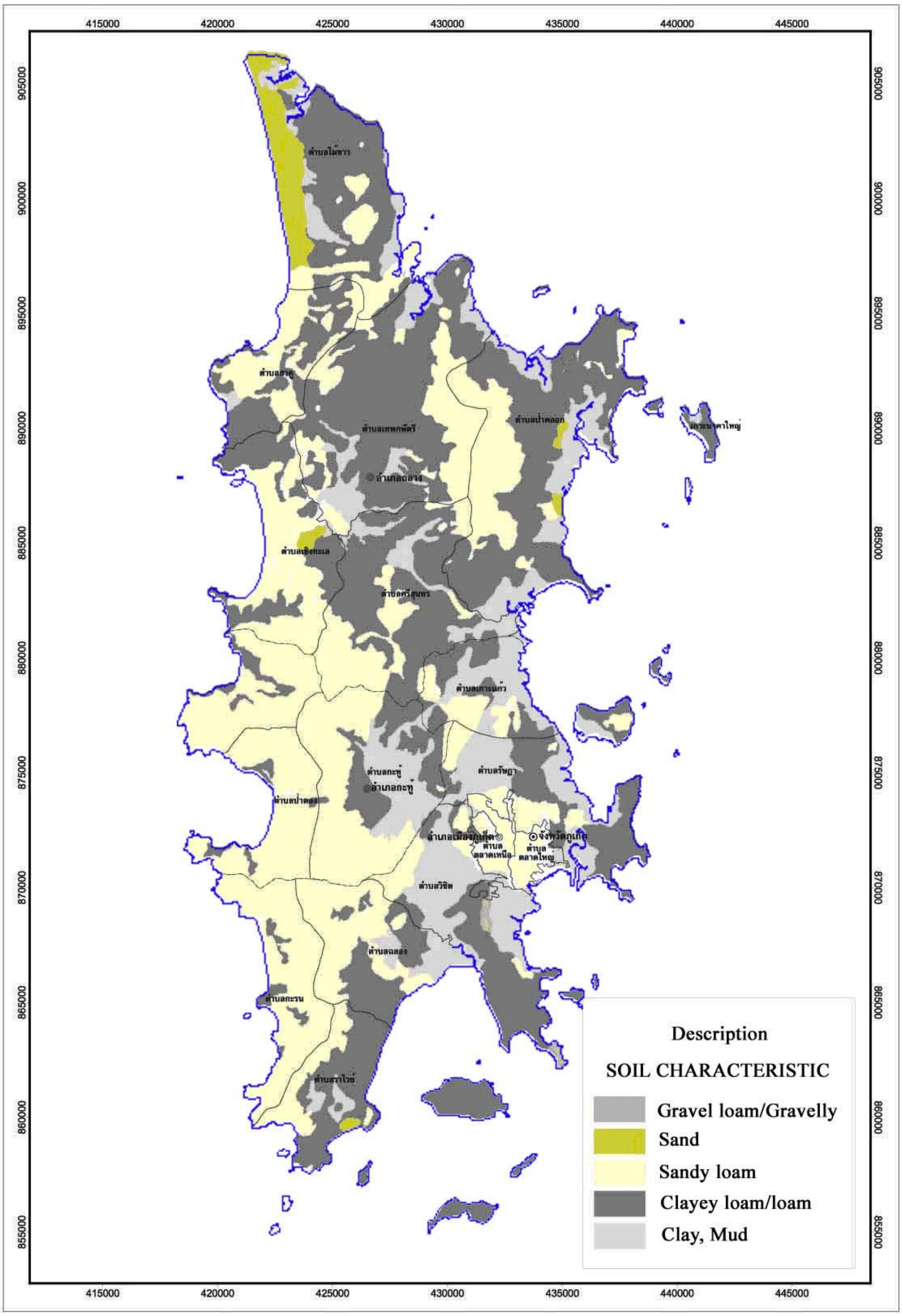


Figure 14 Soil characteristics
Primary data: Department of Land Development (2006)

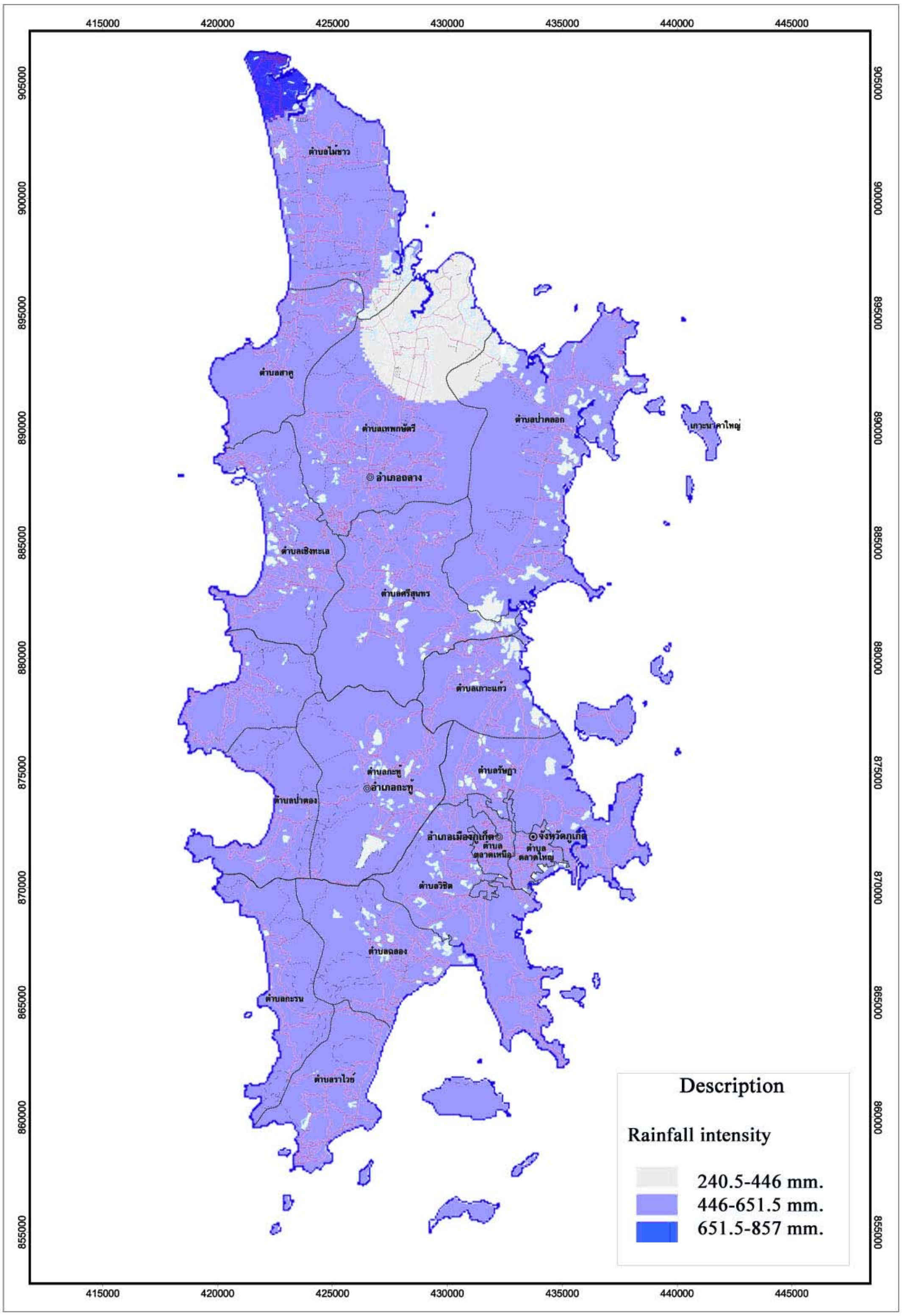


Figure 15 Rainfall intensity
Primary data: Meteorological Department of Thailand, Royal Irrigation Department (2006)

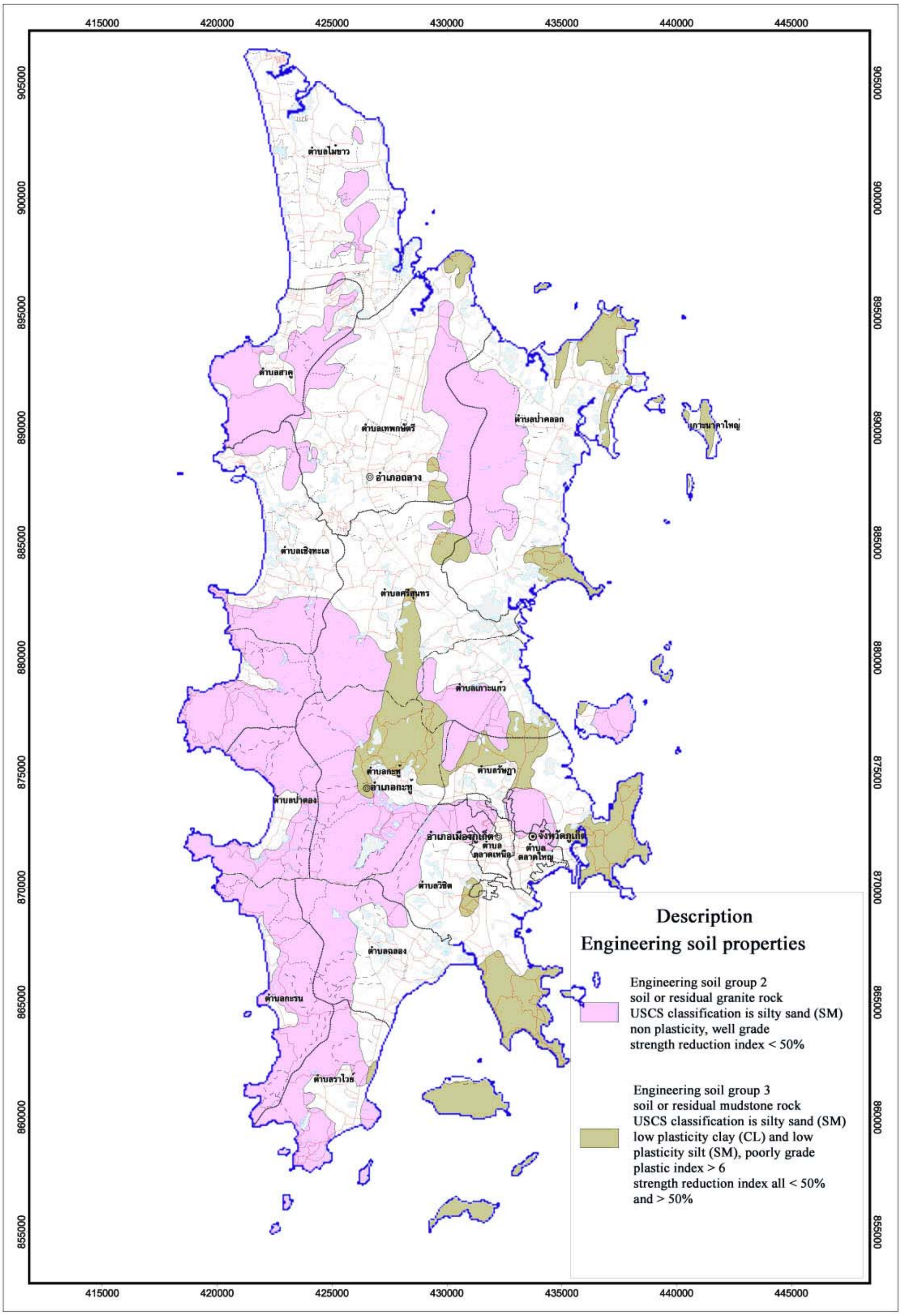


Figure 16 Engineering soil properties
Source: Geotechnical Engineering Research and Development Center (2006)

Weighting Factor Analysis for Landslide Hazard Area

This research is part of the project owned by Department of Mineral Resources and studied by Geotechnical Engineering Research and Development Center, Kasetsart University. Weighting factor method was selected to analyze hazard area. The appropriate weight was assigned to landslide influencing factors by expert opinion. Each of influencing factor was subdivided into subclasses of minor factors and given score number. Each minor factor was assigned score ranging from 1 to 5 according to their increasing in landslide potential. The weighing factor method is appropriate for analyzing the GIS data which gives the result in terms of area based. More accurate result but not appropriate for area-based analysis may be done by geotechnical engineering method.

Major factors used for landslide susceptibility analysis by weighing factor method were

1. Geology (Rock type and Lineament zone)
2. Landform (Slope and Elevation)
3. Surface drainage zone
4. Land use and land cover
5. Soil characteristics
6. Rainfall intensity
7. Engineering soil properties

The detailed descriptions of different rating values of each parameter and sub-parameters as well as the weight value are summarized below.

1. Geology (Rock type and lineament zone)

Rock type is one of the main factors for landslide hazard analysis. Each rock type has different mechanism for landslide. Table 21 shows rock group and is dominate rock in the region. Based on rock group in 6 provinces in southern part of Thailand, rock type can be classified by its landslide potential (Table20).

Table 20 Landslide potential classification of rock type

Rock Type	Landslide Potential Class
Granite Rock	Very high potential
Shale/Mudstone	High potential
Sandstone/Siltstone	Medium potential
Quartzite, Sandstone and Siltstone	Low potential
Limestone/Dolomite	Very low potential

Table 21 Potential landslide level of rock series in 6 provinces **(**By rock type**)**

Potential landslide level	Satun	Phangnga	Krabi	Trang	Ranong	Phuket	Rock type
Very high	Kgr,Tr Jgr, Trgr	Kgr,Tgr, Jgr	Kgr	Trgr	Jgr,Trgr, Kgr	Kgr	Granite Rock
High	Cb,Ck, SD(C)	EP,CP	CP,Tr	CP,SD (C)	CP	CP	Shale/ Mudstone
Medium	E, SD	JK,DC	Mz,JK,TrJ, T	(S)DC ,JK,T, TrJ	SD		Sandstone/Siltstone
Low	C			C	C		Quartzite, Sandstone and Siltstone
Very low	O,P	P	P	Tr,O,P	P		Limestone/ Dolomite

Note: Tr trang - Dolomite mixed Shale and Gravel stone
Tr Krabi –Shale mixed Clay stone and Siltstone

Source: Department of mineral resource (2006)

Lineament zone means fault, fracture and joint. Earth movements involve plastic folding and brittle fracture of rocks, as well as uplift and subsidence. These are tectonic features, caused by large scale movements of crustal plates. Under the high confining pressures at kilometers of depth, and over the long time scales of tectonic processes, most rock may show the plastic deformation, and fractures occur when and where the plastic limits are exceeded. Groundwater is attracted to a fault zone due to the greater conductivity of the fractured and loosened rock to be found in the fault zone. Faults can act as conduits for flow of water, which explains why rocks adjacent to them are often found to be hydro thermally altered. Replacement of original minerals by clays, zeolites, and silica or calcite, as well as precipitation of these minerals in void spaces, grossly changes the character of the rocks near the fault zones, as a result of which stability problems would ensue (Lee. 1995). Influencing of lineament zone is buffered 20 meters from center of lineament line (Thassanapak, 2001).

Table 22 Landslide potential classification of lineament zone

Lineament Zone	Landslide Potential Class
Area inside lineament zone	Very high potential
Area outside lineament zone	Very low potential

2. Landform (Slope and elevation)

Slope is an important factor for landslide susceptibility. Therefore landform or geomorphic is various hill slope characteristics including the relief, steepness of slope, shape of the land surface, slope orientation and aspects, etc. However, only slope gradient and elevation are taken into consideration under the present study due to many limitations.

Table 23 Landslide potential classification of slope

Slope	Landslide Potential Class
Slope > 70%	Very high potential
Slope 50 – 70 %	High potential
Slope 30 – 50 %	Medium potential
Slope 15 – 30 %	Low potential
Slope 0 – 15 %	Very low potential

Elevation is landslide susceptibility factor. Pantanahiran (1994) reported that most of the landslide areas are located between elevation 400-600 meters on Phipun and Kririwong Nakronsrithammarat. Hathaitip (2004) divided elevation in Phuket for landslide hazard analysis as follows:

Table 24 Landslide potential classification of elevation

Elevation	Landslide Potential Class
Elevation > 401 meters	Very high potential
Elevation 301 - 400 meters	High potential
Elevation 201 - 300 meters	Medium potential
Elevation 101 - 200 meters	Low potential
Elevation 0 - 100 meters	Very low potential

3. Surface drainage zone

Surface drainage zone was considered by buffering 10 meters from center of river (Thassanapak, 2001). Groundwater or stream affects the stability of slopes by generating pore pressures, both positive and negative, which alter stress conditions, changing the bulk density of the material forming the slope, developing both internal and external erosions, changing the mineral constituents of the materials forming the slopes (Lee, 1995).

Table 25 Landslide potential classification of surface drainage zone

Surface Drainage Zone	Landslide Potential Class
Area inside Surface drainage zone	High potential
Area outside Surface drainage zone	Very low potential

4. Land used and land cover

Effect of vegetation on slope stability held reduction energy from rainfall. Root of large tree held slope stable. Other deforestation, urban area and agriculture area was cause of slope failure.

Table 26 Landslide potential classification of land used

Land Used	Landslide Potential Class
Agriculture area	High potential
Urban and built-up area	Medium potential
Other deforestation	Low potential
Forest area	Very low potential

5. Soil characteristic

Texture of soil refers to its surface appearance. Soil texture is influenced by the size of the individual particles present in it, divided into gravel, sand, silt, and clay. This study uses soil agricultures group to correlate with drainage (Department of Land Development, 2001).

Table 27 Landslide potential classification of soil characteristic

Soil Characteristic	Landslide Potential Class
Gravel loam/Gravelly sand	Very high potential
Sand	High potential
Sandy loam	Medium potential
Clayey loam/loam	Low potential
Clay, Mud	Very low potential

Table 28 Soil group **(**Department of Land Development, 2001)

Group	Soil characteristics	drainage	Landform (%Slope)
1	Clayey and mud	Poor	Flat (<1%)
2	Clayey and mud	Poor	Flat (<1%)
3	Clayey and mud	Poor	Flat (<1%)
4	Clayey and mud	Poor	Flat (<1%)

Table 28 Soil group (Department of Land Development, 2001) (Continued)

Group	Soil characteristics	drainage	Landform (%Slope)
5	Clayey and mud	Very poor	Flat (<1%)
6	Clayey and mud	Very poor	Flat (<2%)
8	Clayey and mud	Very poor	Flat (<1%)
9	Clayey and mud	Very poor	Coastal (<1%)
10	Clayey and mud	Very poor	Coastal (<1%)
11	Clayey and mud	Very poor	Coastal or Flat (<1%)
12	Clayey and mud	Very poor	Coastal to Flat (<1%)
13	Clayey and mud	Very poor	Coastal (<1%)
14	Clayey and mud	Very poor	Coastal (<1%)
15	Clayey loam and loam	Poor	Flat (<2%)
16	Sandy loam	Good	Flat (<2%)
17	Sandy loam	Poor	Flat (<2%)
18	Sandy loam	Very poor	Flat (<2%)
19	Sandy loam	Poor	Flat (<2%)
20	Sandy loam	Very poor	Flat (<2%)
21	Sandy loam	Fair to poor	River bank or Flat (<1%)
22	Sandy loam	Poor	Flat (<2%)
23	Sand	Very poor	Beach (<2%)
24	Sand	Fair to poor	Flat (<2%)
25	Gravel and gravelly loam	Poor	Flat (<2%)
26	Clayey loam and loam	Good	Plateau to Hill (2-35%)
27	Clayey loam and loam	Good	Plateau to Hill (2-20%)
28	Clayey and mud	Good	Plateau to Flat (<2%)
29	Clayey and mud	Good	Plateau to Hill (2-35%)
30	Clayey and mud	Good	Hill or Mountain (20-50%)
31	Clayey and mud	Fair	Plateau to Hill (2-20%)
32	Clayey loam and loam	Good	Plateau to Hillside (1-12%)

Table 28 Soil group (Department of Land Development, 2001) (Continued)

Group	Soil characteristics	drainage	Landform (%Slope)
33	Sandy loam	Fair	Plateau to Hillside (1-12%)
34	Clayey loam and loam	Fair	Plateau to Steep Slope (2-20%)
35	Sandy loam	Fair	Plateau to Steep Slope (2-20%)
36	Clayey loam and loam	Good	Plateau to Steep Slope (2-20%)
37	Sandy loam	Fair	Plateau to Flat Slope (2-5%)
38	Sandy loam	Good	Plateau to Flat Slope (<2%)
39	Sandy loam	Good	Plateau to Steep Slope (2-20%)
40	Sandy loam	Good	Plateau to Steep Slope (2-20%)
41	Sand	Fair	Plateau to Flat Slope (1-12%)
42	Sand	Fair	Flat to Highland (1-5%)
43	Sand	Very Good	Beach or sand rise (1-5%) Some Hillside
44	Sand	Very Good	Highland to Hillside (2-20%)
45	Gravel and gravelly loam	Good	Highland to Hillside (2-20%)
46	Gravel and gravelly loam	Good	Highland to Steep Slope (2-12%)
47	Clayey loam and loam	Good	Highland to Hillside (5-34%)
48	Sandy loam	Good	Highland to Hillside (12-35%)
49	Sand	Fair	Highland to Flat Slope (2-12%)
50	Gravel and gravelly loam	Good	High land to Hill side (12-35%)
51	Gravel and gravelly loam	Good	Highland to Hillside (12-35%)
52	Clayey loam and loam	Good	Highland to Hillside (2-20%)

Table 28 Soil group (Department of Land Development, 2001) (Continued)

Group	Soil characteristics	drainage	Landform (%Slope)
53	Clayey loam and loam	Good	Plateau to Hillside (2-20%)
54	Clayey and mud	Fair	High land to Steep Slope (5-19%)
55	Clayey and mud	Fair	High land to Flat Slope (1-12%)
56	Clayey loam and loam	Good	Plateau to Hillside (5-34%)
57	Clayey and mud	Very poor	Flat (<1%)
58	Clayey and mud	Very poor	Flat (<1%)
59	Clayey and mud	Very poor	Flat in valley (<2%)
60	Sandy loam	Good	Highland to Flat Slope (1-12%)
61	Slope complex		Highland to Steep Slope (5-19%)
62	Slope complex		Steep Slope (>35%)

6. Rainfall intensity

The magnitude, intensity, and duration of storm all play role in determination whether a hill slope will fail. Excessive rainfall weakens earth materials by displacing air and increasing the pore water pressure along shear surface. This study used two kinds of rainfall intensity which are 3 days cumulative of 1 year return period rainfall and 3 days cumulative of 1, 5, 20, 50, 100 years return period rainfall.

Table 29 Landslide potential classification of rainfall intensity (3 days cumulative rainfall for 1 year return period)

Rainfall Intensity	Landslide Potential Class
Rainfall intensity > 203 mm.	Very high potential
Rainfall intensity 161 - 203 mm.	High potential
Rainfall intensity 119 - 161 mm.	Medium potential
Rainfall intensity 77 - 119 mm.	Low potential
Rainfall intensity 35 – 77 mm.	Very low potential

Table 30 Landslide potential classification of rainfall intensity (3 days cumulative rainfall for 1, 5, 20, 50, 100 years return period)

Rainfall Intensity	Landslide Potential Class
Rainfall intensity > 857 mm.	Very high potential
Rainfall intensity 651.5 - 857 mm.	High potential
Rainfall intensity 446 – 651.5 mm.	Medium potential
Rainfall intensity 240.5 - 446 mm.	Low potential
Rainfall intensity 35 – 240.5 mm.	Very low potential

7. Engineering soil properties

Landside susceptibility factor from engineering soil properties was studied by using index of unstable soil. Appendix table 3 - 4 show a laboratory test of soil and weathered rock consisting of Undisturbed, Disturbed and Pocket Penetrometer Test. These were parallel study results which were used for divided landslide potential levels. The soil engineering properties were classified in term of parent rocks or residual soil. The engineering soil properties were different from rock type parameter. Residual soil from sandstone/siltstone has strength reduction when considered at natural water content with saturated condition more than residual soil from granite rock (Appendix table 4). But it was different from soil characteristics because the engineering soil properties were soil engineering and soil characteristics and soil textures in which primary data were collected from agricultural soil.

Table 31 Landslide potential classification of engineering soil properties

Engineering Soil Properties	Landslide Potential Class
Residual soil form Sandstone/Siltstone	Very high potential
Residual soil form Granite Rock	High potential
Residual soil form Shale/Mudstone	Medium potential
Residual soil form Quartzite, Sandstone and Siltstone	Low potential
Residual soil form Limestone/Dolomite	Very low potential

The 7 related factors were used for landslide hazard analysis by weighing factor method. The assigned weight system to parameters influencing the landslide in Phuket are summarized and presented in Table 32. Table 33 shows the landslide potential and the range of a total score for all return periods of rainfall.

Table 32 The numerical weight assignment to the parameters influencing the landslide potential in Phuket

<table>
<tr><th rowspan="2">Parameter</th><th colspan="2">Weight Value</th><th colspan="3">Rating Value</th></tr>
<tr><th>Parameter</th><th>Sub-parameter</th><th colspan="2">Description</th><th>Rating (1-5)</th></tr>
<tr><td>1. Geology</td><td>5</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>1.1 Rock Type</td><td></td><td>3</td><td colspan="2">A. Granite Rock</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. Shale/Mudstone</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">C. Sandstone/Siltstone</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">D. Quartzite, Sandstone and Siltstone</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">E. Limestone/Dolomite</td><td>1</td></tr>
<tr><td>1.2 Lineament zone</td><td></td><td>2</td><td colspan="2">A. Area inside lineament zone</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. Area outside lineament zone</td><td>1</td></tr>
<tr><td>2. Landform</td><td>4</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>2.1 Slope (%)</td><td></td><td>3</td><td colspan="2">A. >70%</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. 50-70%</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">C. 30-50%</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">D. 15-30%</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">E. 0-15%</td><td>1</td></tr>
<tr><td>2.2 Elevation (meter)</td><td></td><td>1</td><td colspan="2">A. >400 m</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. 300-400 m</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">C. 200-300 m</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">D. 100-200 m</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">E. 0-100 m</td><td>1</td></tr>
<tr><td>3. Surface drainage</td><td>2</td><td></td><td colspan="2">A. Area inside surface drainage zone</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. Area outside surface drainage zone</td><td>1</td></tr>
<tr><td>4. Soil characteristics</td><td>2</td><td></td><td colspan="2">A. Gravel loam/Gravelly sand</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. Sand</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">C. Sandy loam</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">D. Clayey loam/loam</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">E. Clay, Mud</td><td>1</td></tr>
<tr><td>5. Land use and land cover</td><td>3</td><td></td><td colspan="2">A. Agriculture area</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. Urban and built-up area</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">C. Other deforestation</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">D. Forest area</td><td>1</td></tr>
<tr><td>6. Rainfall intensity</td><td>5</td><td></td><td>Return period 1 year</td><td>Return period 1,5,20,50,100 years</td><td></td></tr>
<tr><td></td><td></td><td></td><td>A. >203 mm.</td><td>>857 mm.</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td>B. 161-203 mm.</td><td>651-827 mm.</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td>C. 119-161 mm.</td><td>446-651 mm.</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td>D. 77-119 mm.</td><td>240-446 mm.</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td>E. 35-77 mm.</td><td>35-240 mm.</td><td>1</td></tr>
<tr><td>7. Engineering soil properties (in term of parent rocks)</td><td>4</td><td></td><td colspan="2">A. Weathered Sandstone/ Siltstone</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">B. Weathered Granite Rock</td><td>4</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">C. Weathered Shale/Mudstone</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">D. Weathered Quartzite, Sandstone and Siltstone</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">E. Weathered Limestone/ Dolomite</td><td>1</td></tr>
</table>

Table 33 The landslide potential and the range of total score for all return periods of rainfall

Landslide Susceptibility Classes	Range of Score
Very high susceptibility to landslide	101-120
High susceptibility to landslide	82-101
Moderate susceptibility to landslide	63-82
Low susceptibility to landslide	44-63
Very low to nil susceptibility to landslide	25-44

Processing of landslide susceptibility and hazard map (7 factors)

In determining the numerical rating of altogether 7 parameters/sub-parameters responding to the landslide in Phuket, an area of 25x25 square meters grid cell has been employed for the analysis by GIS program. After that, the weight-rating values of each parameter/sub-parameters or each derivative map will be determined in each square grid cell. Finally, the scores of weight-rating in each 25x25 square meters grid cell will be obtained from the summation of weight-rating values of each derivative map. These means that the overall areas of Phuket are subdivided into a small 25x25 square grid cell. The landslide susceptibility factors are shown in Fig 8- Fig 16. Landslides susceptibility analysis was produced from difference factor for comparison of each map in Fig 17.

The results of processing of landslide susceptibility map considered by weighting factor analysis are shown in Fig 18. Plan area was classified by landslide susceptibility class shown in Table 34 and Fig 19.

Fig 20 – Fig 24 shows the results of processing of landslide hazard map considered by weighting factor analysis in terms of probability of return period of rainfall. Scores were classified by half of range between 25 to 120 which was 73 score. Fig 25 shows landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considering 7 related factors. Predicted landslide hazard area for 5 return periods of rainfall considering 7 related factors is shown in Table 35 and Fig 26. The plan area of landslide hazard was 4.14%, 7.68%, 14.15%, 16.29% and 18.59% for 1, 5, 20, 50 and 100 years return period of rainfall respectively in which the plan area of landslide hazard for 1 year return period overlap with plan area of landslide hazard for 5, 20, 50 and 100 year return period.

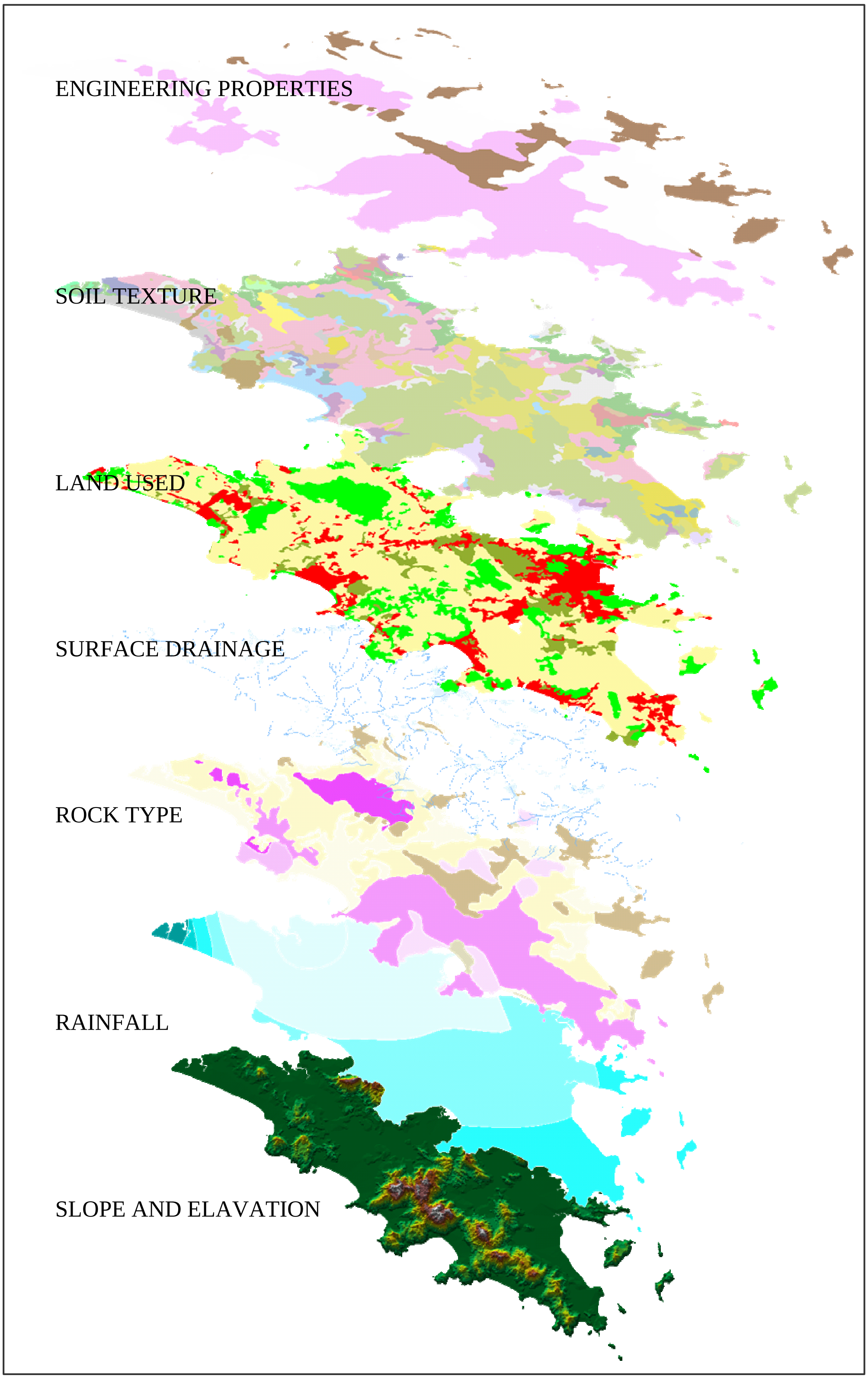


Figure 17 GIS layers of considered factors
Source: Department of mineral resource (2006)

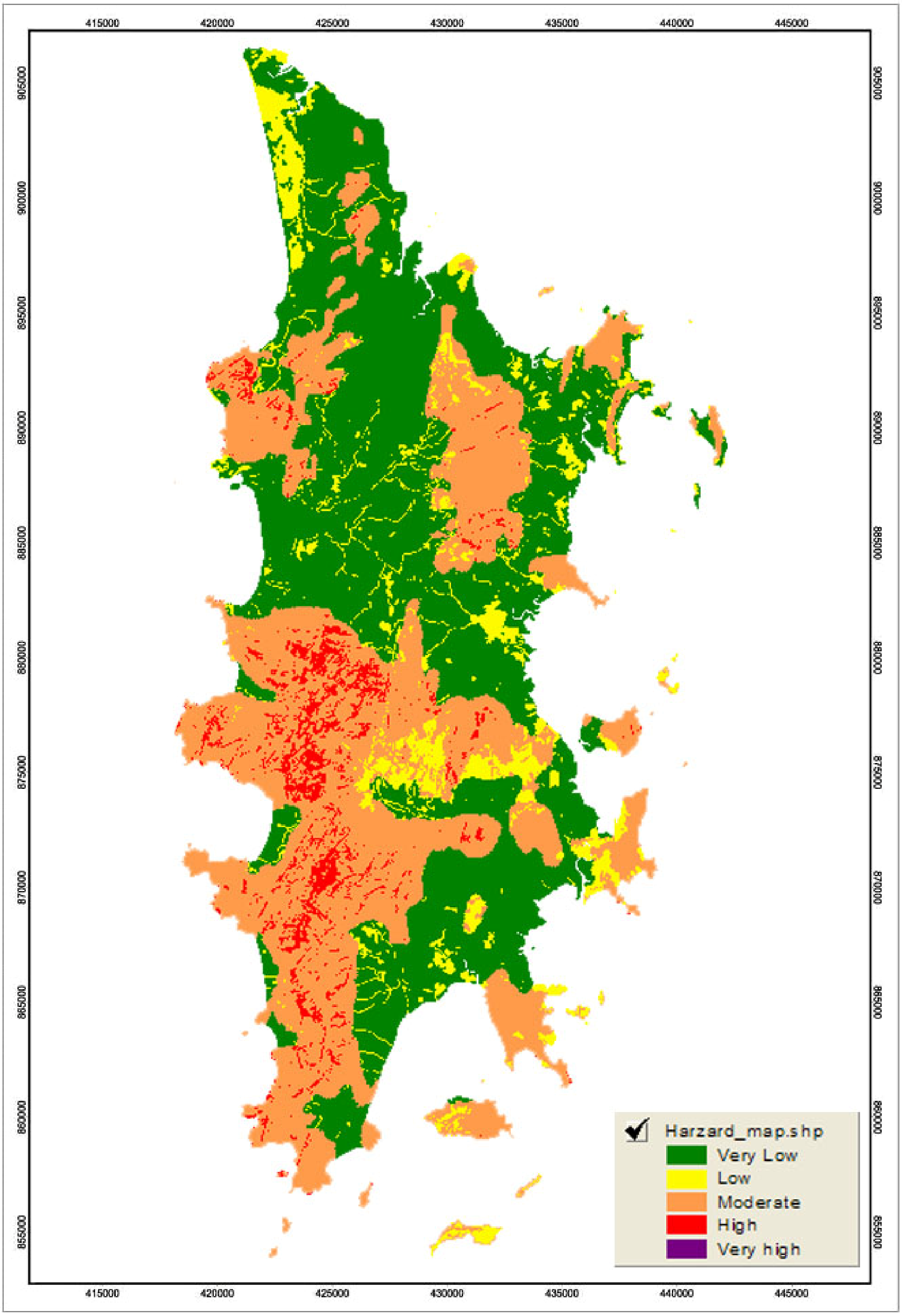


Figure 18 Landslide susceptibility map by weighting factor method considered 7 related factors

Table 34 Predicted landslide susceptibility area considering 7 related factors

Score	Landslide Potentials Classes	pixel	Area (km^2)	%
101-120	Very high potential	1	0.00	0.00
82-101	High potential	49,234	30.77	5.60
63-82	Moderate potential	353,056	220.66	40.19
44-63	Low potential	101,342	63.34	11.54
25-44	Very low to nil potential	374,784	234.24	42.67
	Sum	878,417	549	100.00

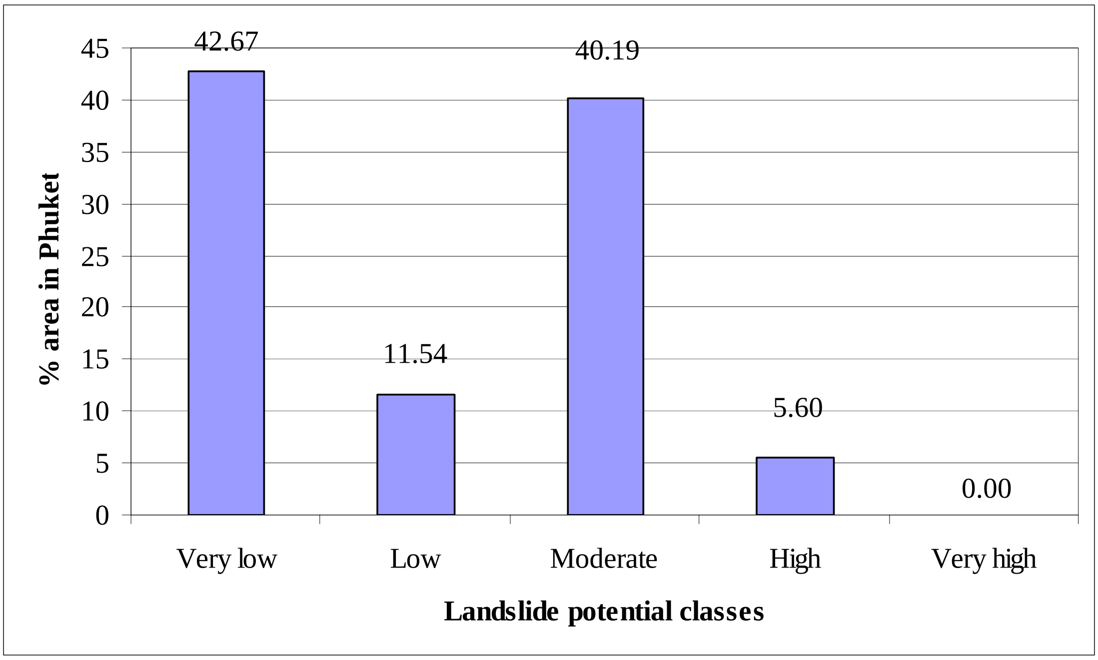


Figure 19 Predicted landslide susceptibility area considering 7 related factors

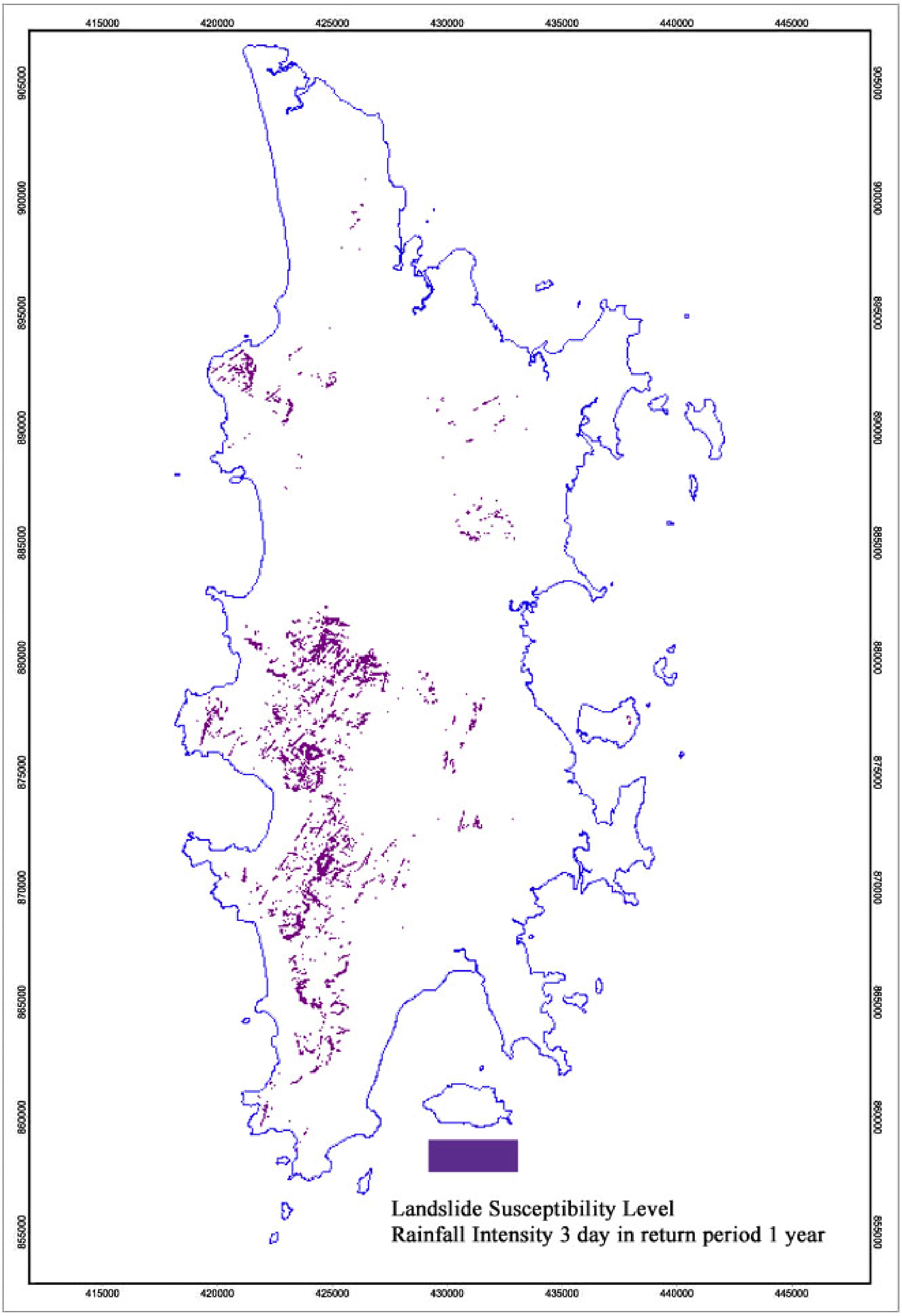


Figure 20 Landslide hazard map considering 1 year return period of rainfall

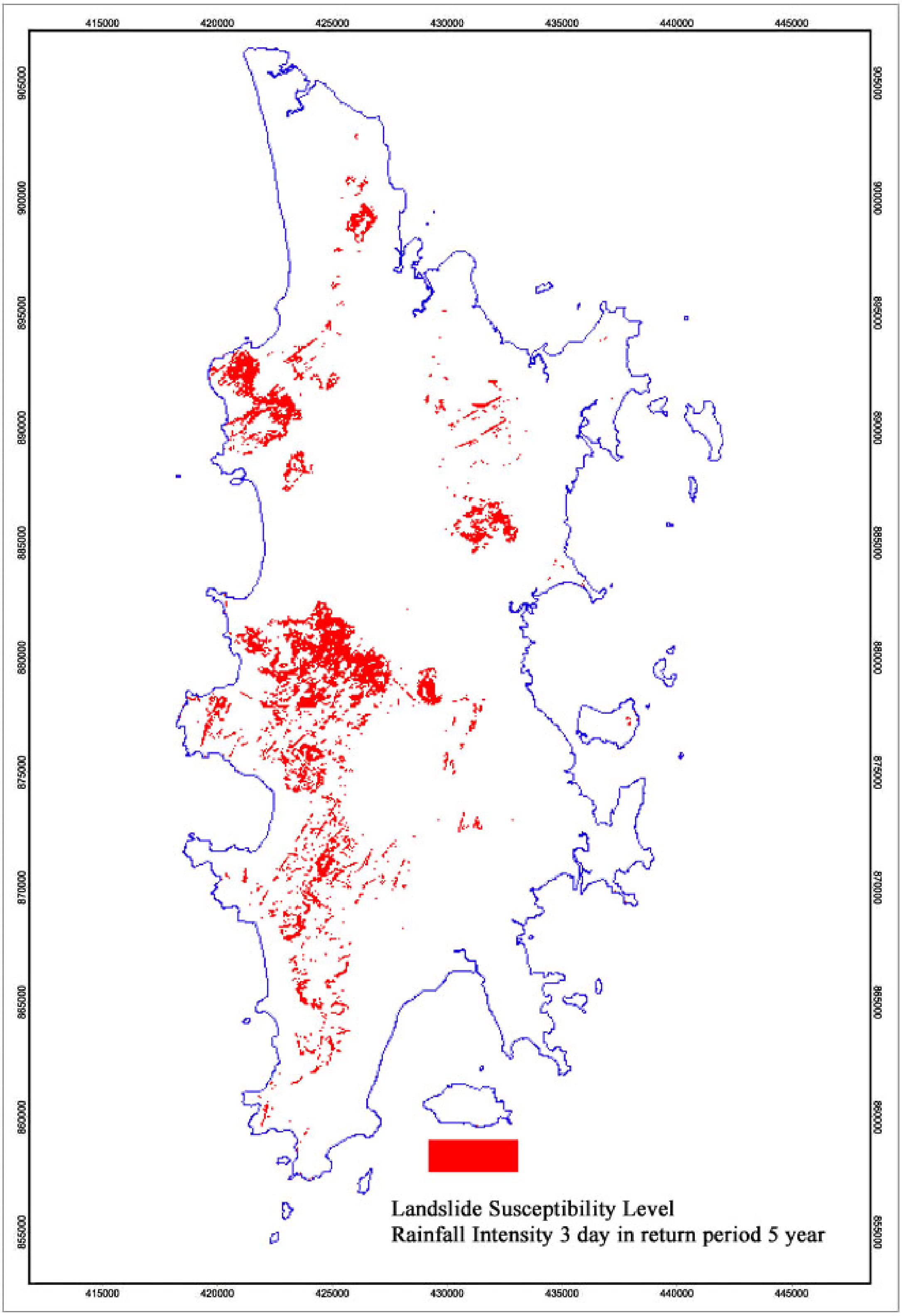


Figure 21 Landslide hazard map considering 5 years return period of rainfall

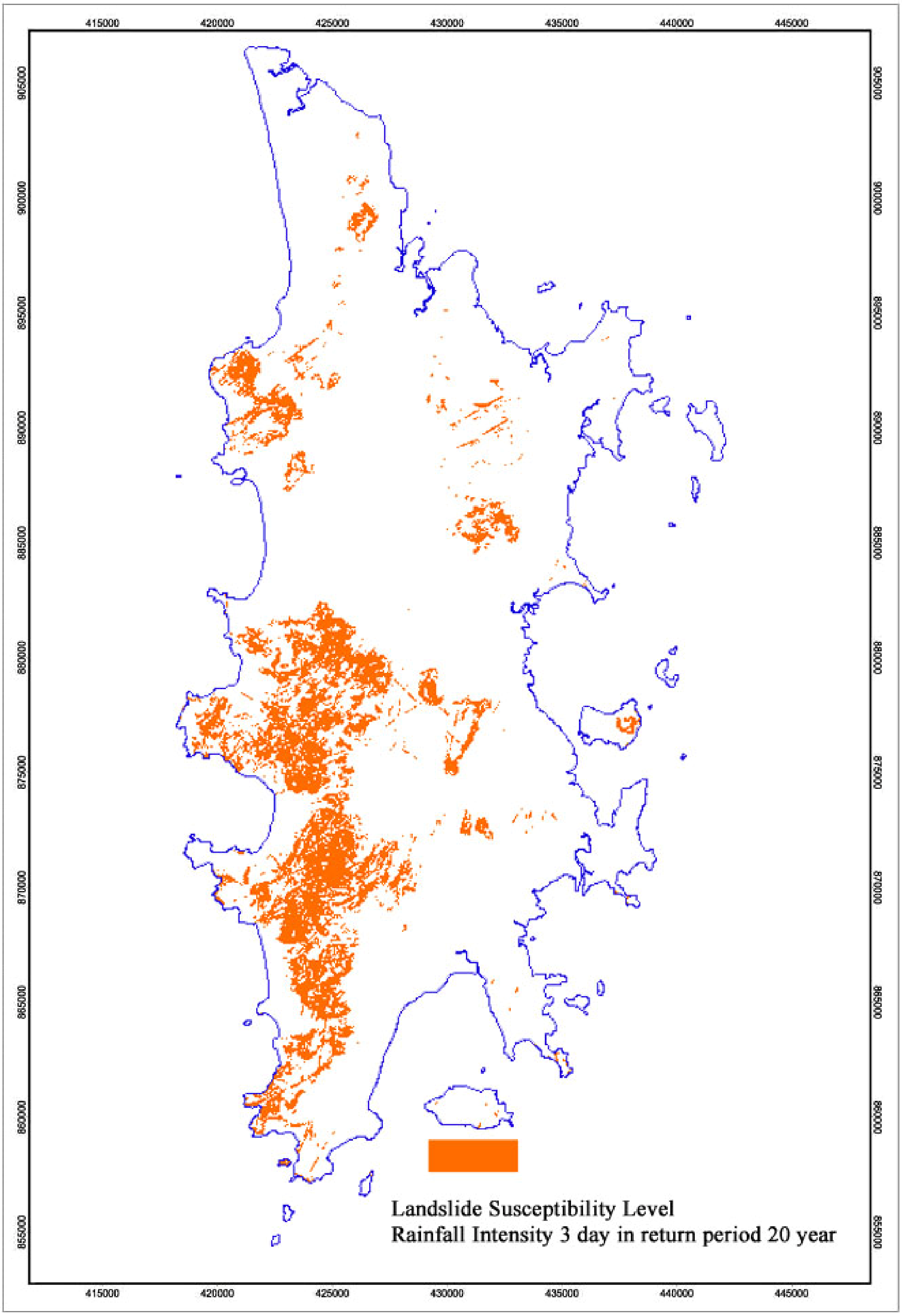
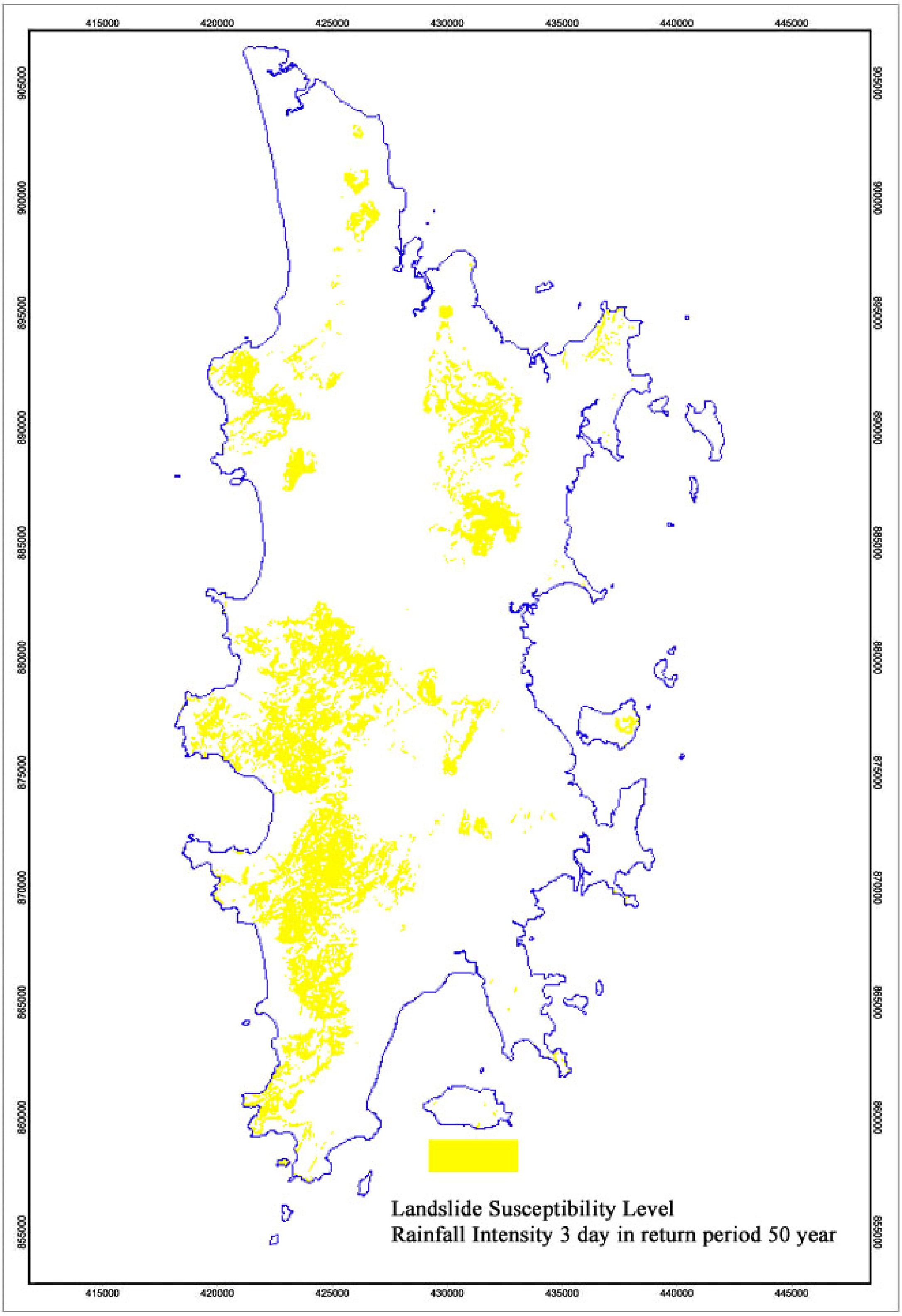


Figure 22 Landslide hazard map considering 20 years return period of rainfall



<u>Figure 23</u> Landslide hazard map considering 50 years return period of rainfall

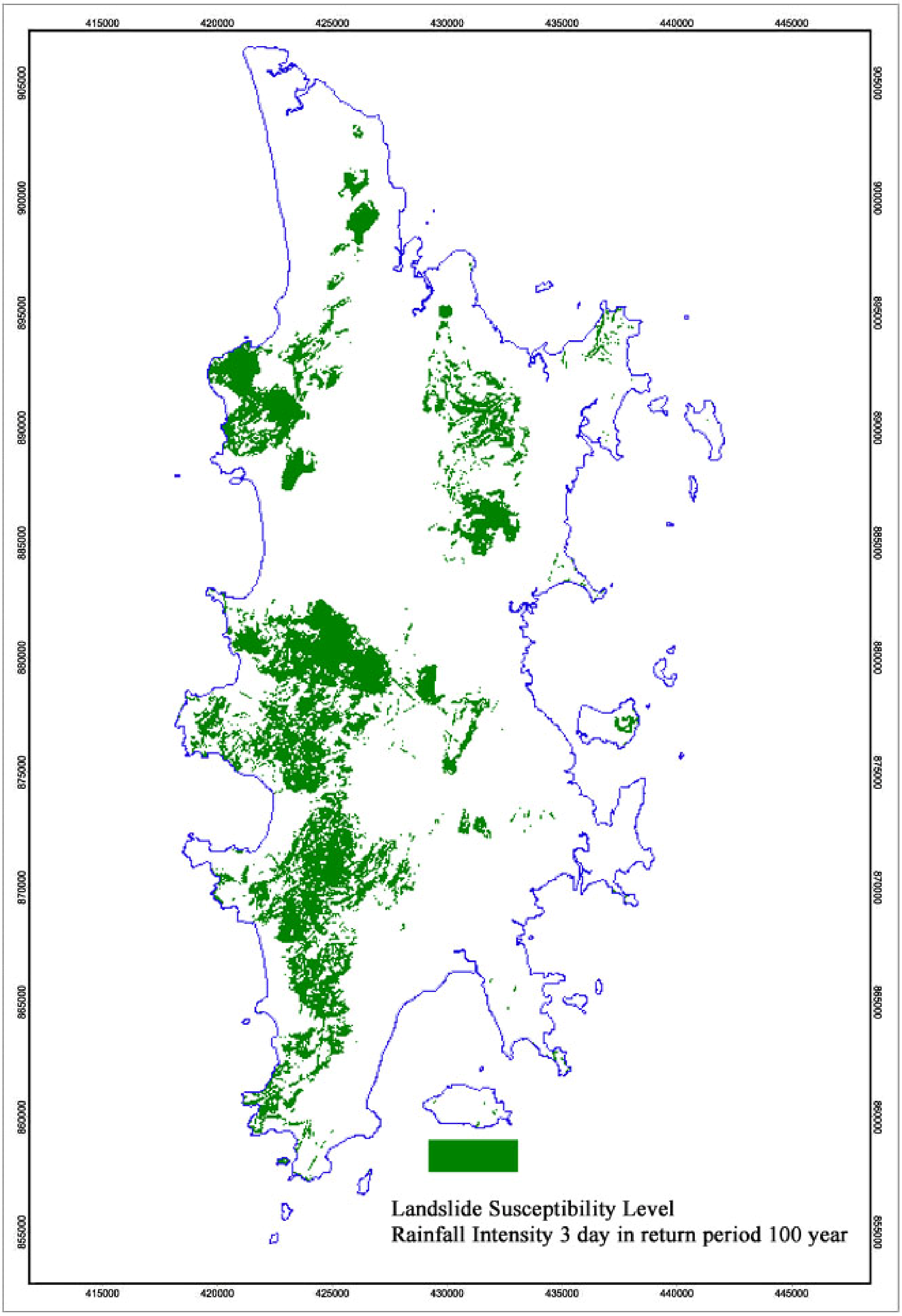


Figure 24 Landslide hazard map considering 100 years return period of rainfall

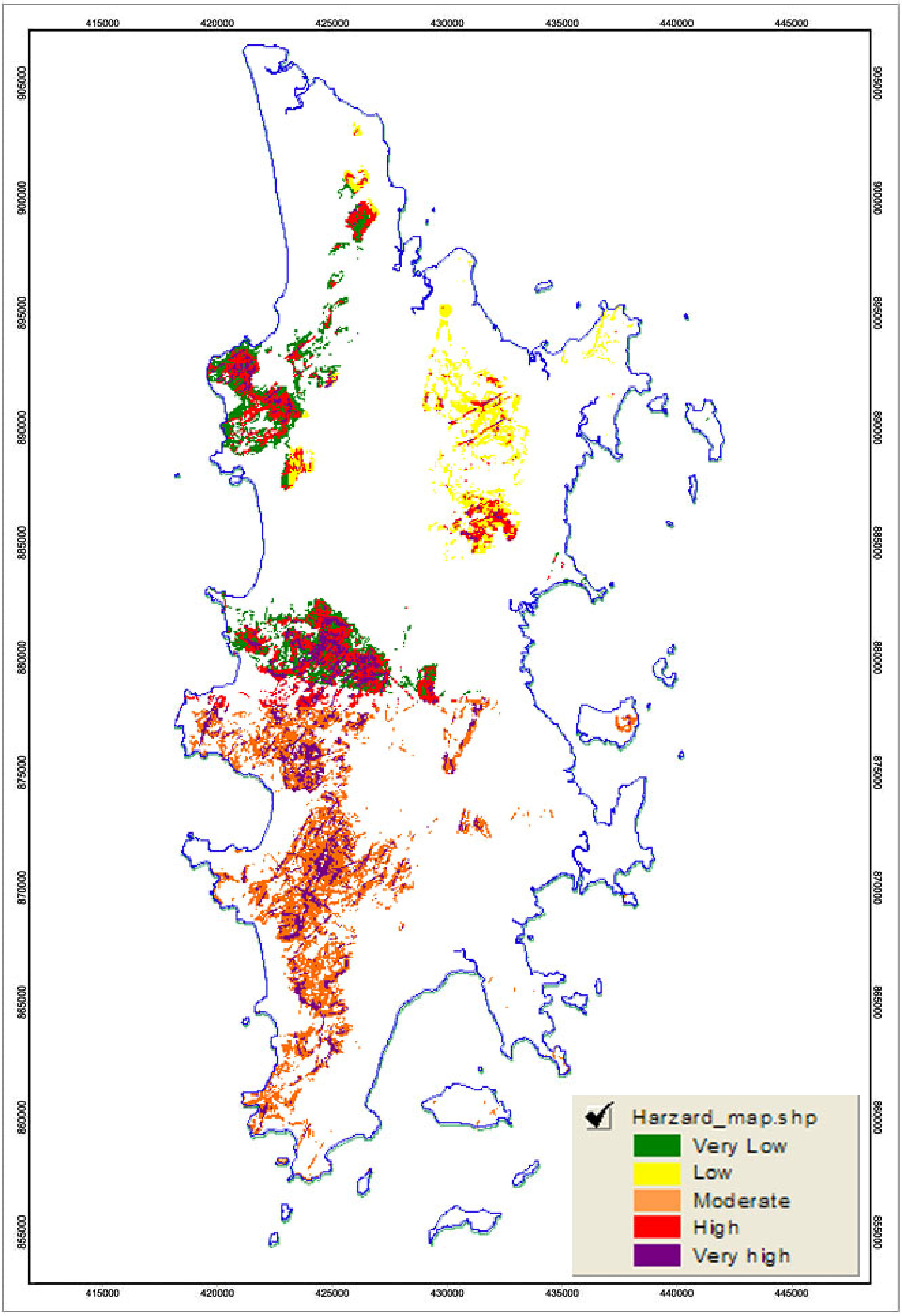


Figure 25 Landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors

Table 35 Predicted landslide hazard area for 5 return periods of rainfall considering 7 related factors

Return period of rainfall year	Landslide classify	pixel	Area (km^2)	%
1	Fail	36,329	22.71	4.14
	No fail	842,088	526.31	95.86
5	Fail	67,480	42.18	7.68
	No fail	810,937	506.84	92.32
20	Fail	124,302	77.69	14.15
	No fail	754,115	471.32	85.85
50	Fail	143,130	89.46	16.29
	No fail	735,287	459.55	83.71
100	Fail	163,268	102.04	18.59
	No fail	715,149	446.97	81.41

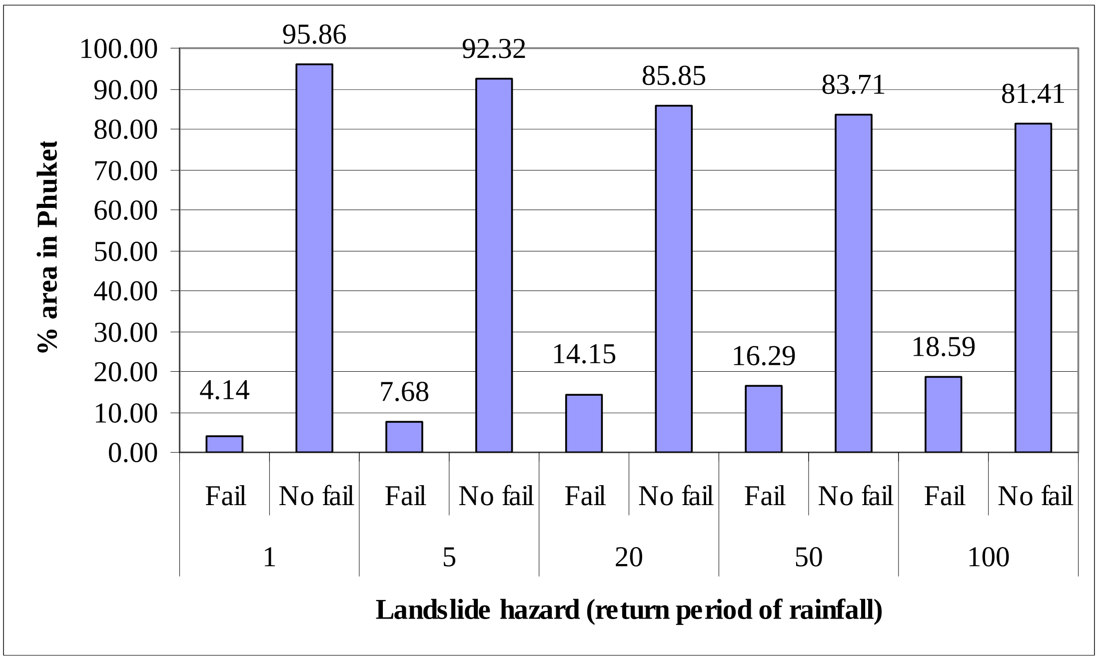


Figure 26 Predicted landslide hazard area for 5 return periods of rainfall considering 7 related factors

Table 36 Comparison of landslide potential area and landslide hazard area considering 7 related factors

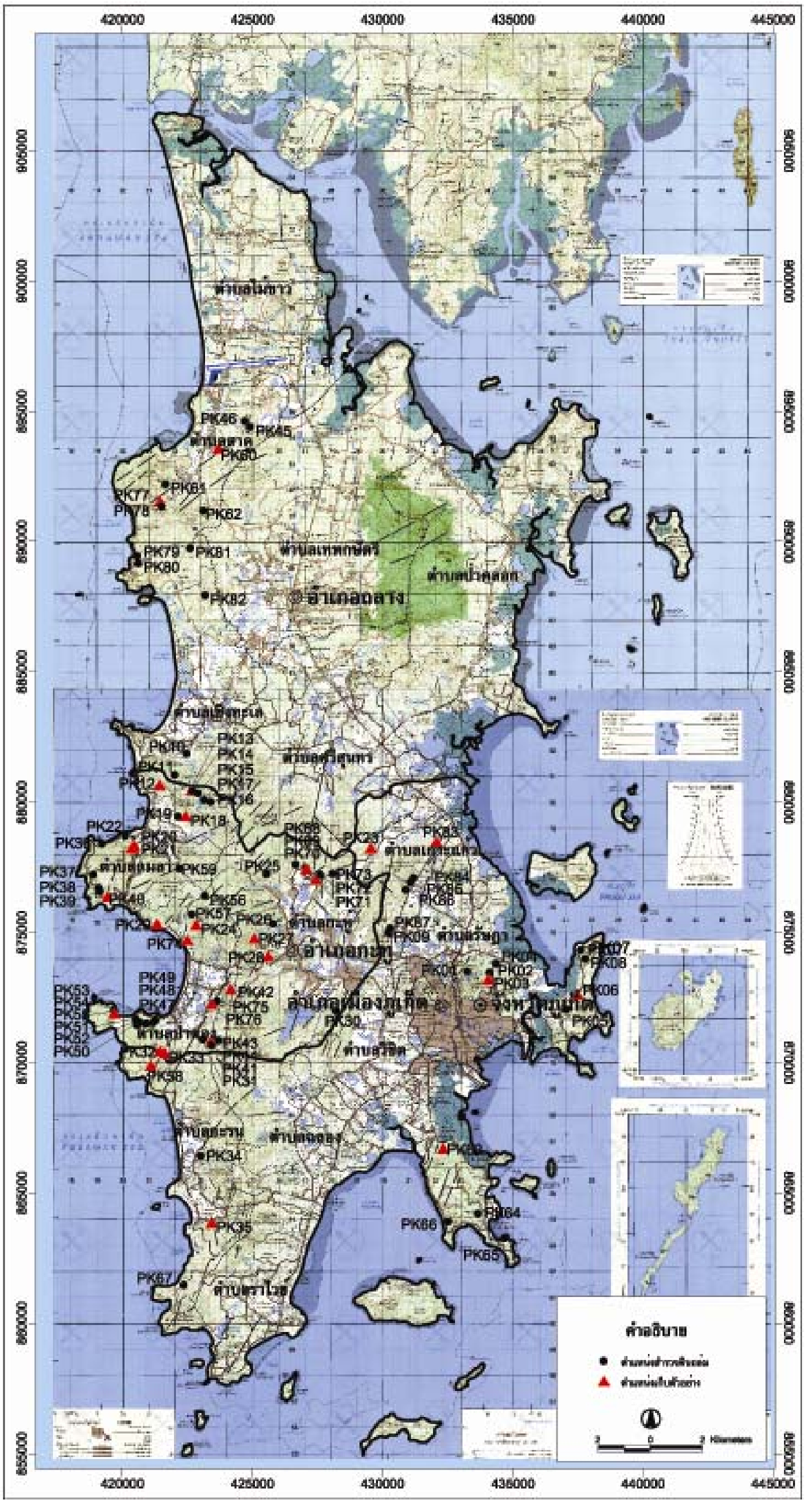
Landslide Potentials Classes	Landslide susceptibility map (%)	Landslide hazard map (%)
Very high	0.00	4.14
High	5.60	7.68
Moderate	40.19	14.15
Low	11.54	16.29
Very low	42.67	18.59
Sum	100.00	

The comparison of predicted landslide susceptibility and landslide hazard area considered 7 related factors shows in Table 36 which was evaluated by same weighting factor method but the results were different. When considered annual probability in case of landslide susceptibility has no area in very high landslide potentials classes but landslide hazard has area in very high landslide potentials classes, the landslide potentials classes of landslide susceptibility mean in annual probability but landslide hazard mean 1.0, 0.2, 0.05, 0.02 and 0.01 annual probability for 1, 5, 20, 50 and 100 years return period of rainfall respectively.

Field Investigation

The physiographic setting of Phuket Island is underlying mostly the granitic mountain range approximately 40 percent of the total area, especially the western side of the island. The highest elevation of the hillslope are 541 m MSL at Khao Khun Wa and 515 m MSL at Khao Mai Tao Sip Song on the western part of the area and slope steepness more than 30 degrees (Thassanapak, 2001). Inventory map was produce by field investigation. Fig 27 shows field survey location in Phuket. Field survey consisted of 87 points, which are located in watershed map (Table 37 and Appendix table 1).

Most of field investigation was cut slope for development which had a little bit natural landslide. There are numerous failure slope developments in weathered granite which have caused damage to adjacent building (Fig 28). There are numerous road cuts across these granite hill slopes (Fig 29 and Fig 30). Hillside cuts required for highway construction often destabilize slope gradient of the hill slope. Most of these failures tend to be earth flow or earth slump (Fig 31). The slope failure revealed that the earth materials were the weathered granitic rock (Fig 32). An attempt to remedy and control these failures is seen along Highway no. 4233, especially the route between Kamala beach and Patong beach and along the distance from Patong beach to Karon beach (Fig 33). And cut slope for residential or commercial building is very close; some cases show failure (Fig 35), some cases still did not (Fig 34) depending on degree of weathering rock.



Note: PKxx is field survey location

<u>Figure 27</u> Location of field investigation
Source: Department of mineral resource (2006)

Figure 28 Station PK32 cut slope for borrow area in Patong Kathu, N 870435 E 421425. The rock is granite (G2). Rock slump failure mode.

Figure 29 Station PK85 cut slope for highway construction number 0402 in Ratsada Muang, N 876928 E 430877. The rock is granite (G4). The slope is still stable.

Figure 30 Station PK38 cut slope for road along Ao Na Khale in Kamala Kathu (Khao Pak Bang), N 876700 E 419075. The rock is granite (G2). The slope failed by soil.

<u>Figure 31</u> Station PK39 cut slope for road along Ao Na Khale in Kamala Kathu (Khao Pak Bang), N 876570 E 419110. The rock is granite (G2). The slope failed by soil.

<u>Figure 32</u> Station PK40 cut slope for road along Ao Na Khale in Kamala Kathu (Khao Pak Bang), N 876360 E 419400. The rock is granite (G4). The slope failed by soil.

Figure 33 Station PK20 cut slope for highway construction number 4233 between Kamala-Patong beach, N878200 E420400. The rock is granite (G2). Conventional rotation failure.

Figure 34 Station PK09 cut slope for highway construction number 0402 in Ratsada Muang, N 875000 E 430200. The rock is granite (G4). The slope is still stable.

Figure 35 Station PK35 cut slope for housing construction between road number 4233 and 4028 in Karon Muang, N 863850 E 423400. The rock is granite (G2). The slope failed by soil.

Watershed Analysis

Result from field investigation evaluated by 24 watersheds. This study surveyed only 14 watersheds in Table 37 and Fig 36-37. Field surveys emphasized to collected fail or no fail of cut slope but in table natural landslide were included.

Table 37 Field investigation in 14 watersheds

No.	Watershed	Area (km^2)	No. Observation	FAIL	NO FAIL
1	AO KUNG BASIN	21.57			
2	AO PO BASIN	31.58			
3	CHALONG BASIN	43.44	1	-	1
4	CHAT CHAI BASIN	28.81			
5	KAMALA BASIN	18.05	17	15	2
6	KARON BASIN	9.27	1	-	1
7	KATA BASIN	4.68	1	1	-
8	KATA NOI BASIN	2.20	1	1	-
9	KHAO KHAT BASIN	3.03			
10	KHOCHAO BASIN	1.31			
11	LAEM KHAEK BASIN	1.97	3	2	1
12	LAEM NGA BASIN	11.73	6	4	2
13	LEAM MAI NGANG BASIN	1.58			
14	LEAM YANG BASIN	4.42			
15	MUANG BASIN	90.13	21	2	19
16	MUM NAI BASIN	1.06			
17	MUM NOK BASIN	5.73			
18	NA KHALE BASIN	3.89	1	1	-
19	PATONG BASIN	18.85	20	11	9
20	RAWAI BASIN	6.94			
21	SAPAM BASIN	64.68	2	-	2
22	THA MAPHRAO BASIN	40.74	1	-	1
23	THALANG BASIN	85.41	6	1	5
24	THUNG NUNG BASIN	17.40	6	1	5
25	SMALL ISLANDS	23.24			
	SUMMATION	541.71	87	39	48

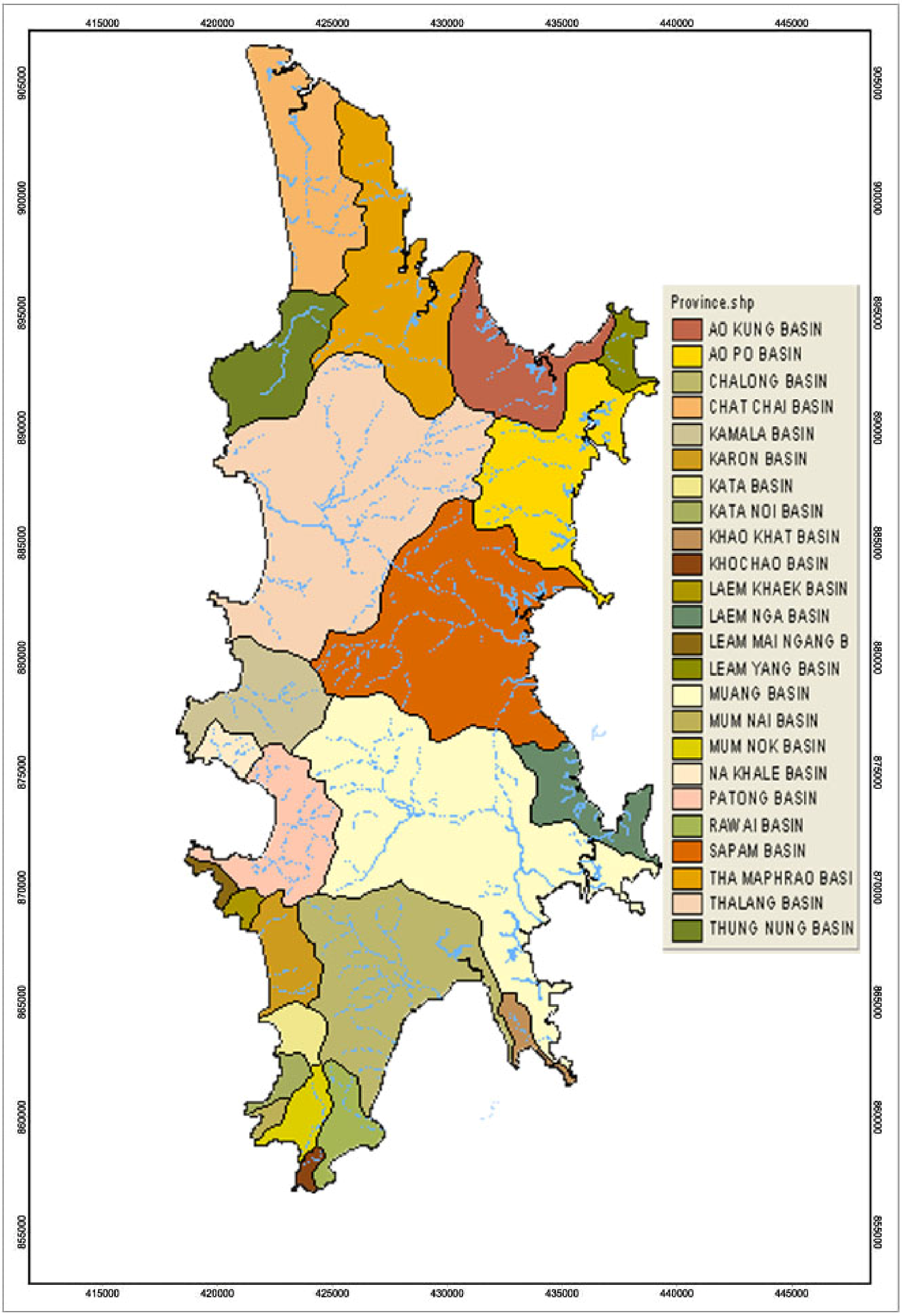


Figure 36 Watershed and surface water resources in Phuket
Source: Department of Environmental Quality Promotion (2004)

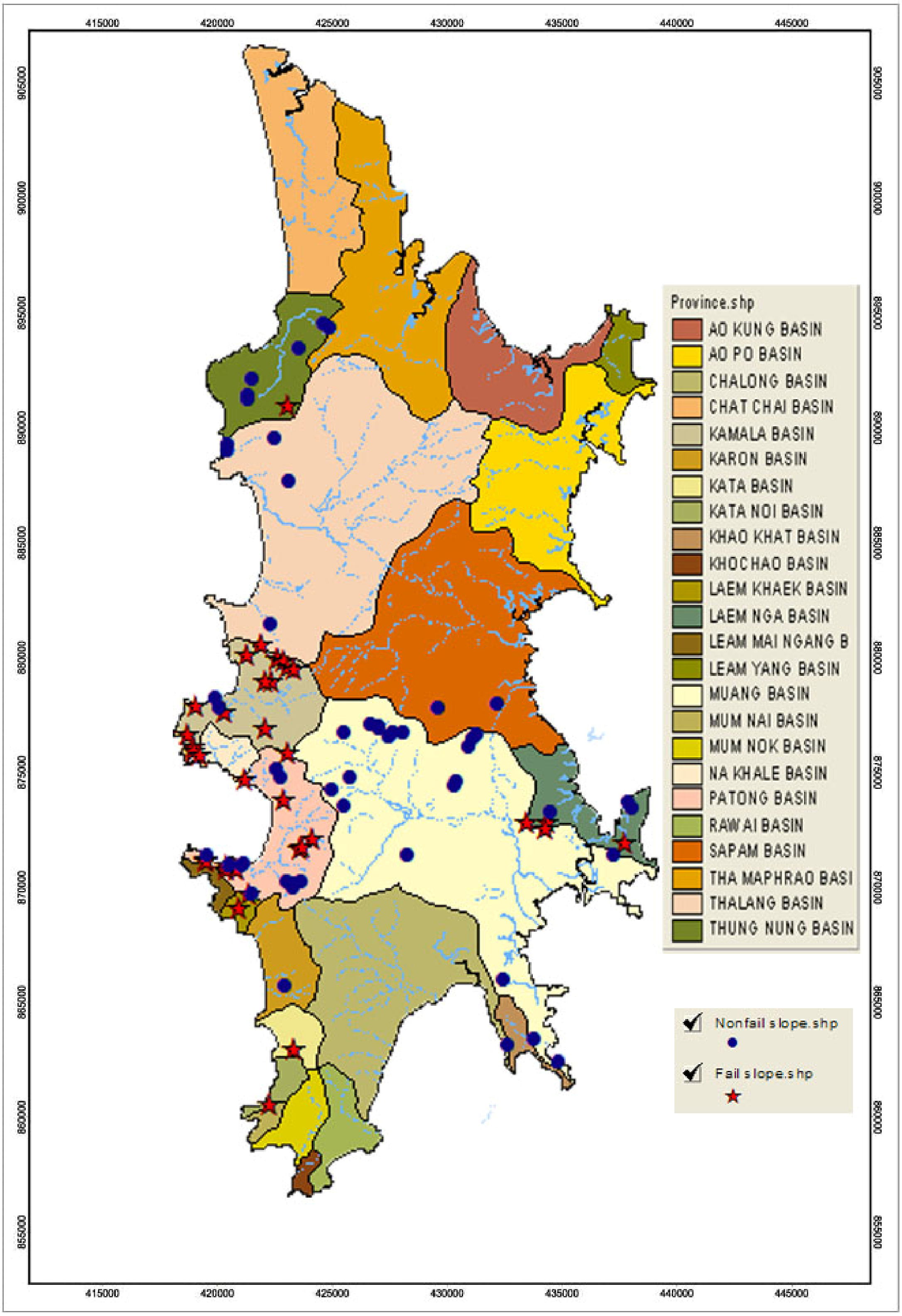


Figure 37 Field survey locations, cut slope condition

Weight Factor Analysis Including RMR Value

Table 38 and Appendix table 1 show RMR rating estimation from field investigation data. Table 39 shows average rock mass rating classified by rock type.

Table 38 Field investigation data for RMR rating

NO.	**Parameter**	**In Field+Lab**				
		kalim	**DTAC**	**sire'**	**patong 50 yrs**	**gabion 2**
1	point-load	2.46 MPa	2.94 Mpa	-	7.92 Mpa	1.19 Mpa
2	RQD	73.47%	69%	0%	87%	20%
3	spacing of discontinuities	200-300 mm	300-600 mm	100 mm	200-600 mm	200-300 mm
4	condition of discontinuities					
	4.1 discontinuities length	> 20 m	> 20 m	> 20 m	> 20 m	> 20 m
	4.2 separation	1-2 mm	1-2 mm	< 1 mm	0.1-1 mm	1-3 mm
	4.3 roughness	Slightly rough	Slightly rough	Smoooth	Rough	Slightly rough
	4.4 infilling	Soft < 5 mm	Soft < 5 mm	Soft < 5 mm	None	Soft < 5 mm
	4.5 weathering	highly weathered	Moderately weathered	highly weathered	highly weathered	highly weathered
5	general condition	Damp	Damp	Damp	Damp	Damp
B	slope	Fair	Fair	Unfavourable	Fair	Very Unfavourable

Table 39 Average rock mass rating classified by rock type

Rock type	BASIN	Number	Avg. RMR
CP	CHALONG BASIN	1	55.00
	LAEM NGA BASIN	4	47.50
	MUANG BASIN	9	51.00
G2	KAMALA BASIN	14	35.50
	KARON BASIN	1	60.00
	KATA BASIN	1	47.00
	KATA NOI BASIN	1	32.00
	MUANG BASIN	4	60.75
	PATONG BASIN	13	46.07
	THA MAPHRAO BASIN	1	60.00
	THALANG BASIN	2	54.00
	THUNG NUNG BASIN	2	56.00
G3	THUNG NUNG BASIN	3	47.00
	THALANG BASIN	3	57.00
G4	LAEM KHAEK BASIN	3	34.67
	MUANG BASIN	5	59.80
	NA KHALE BASIN	1	45.00
	PATONG BASIN	6	42.33
	SAPAM BASIN	2	64.50

Fig 38 shows relationship between failure of cut slope and RMR value. Fig 39 shows relationship between non-failure of cut slope and RMR value.

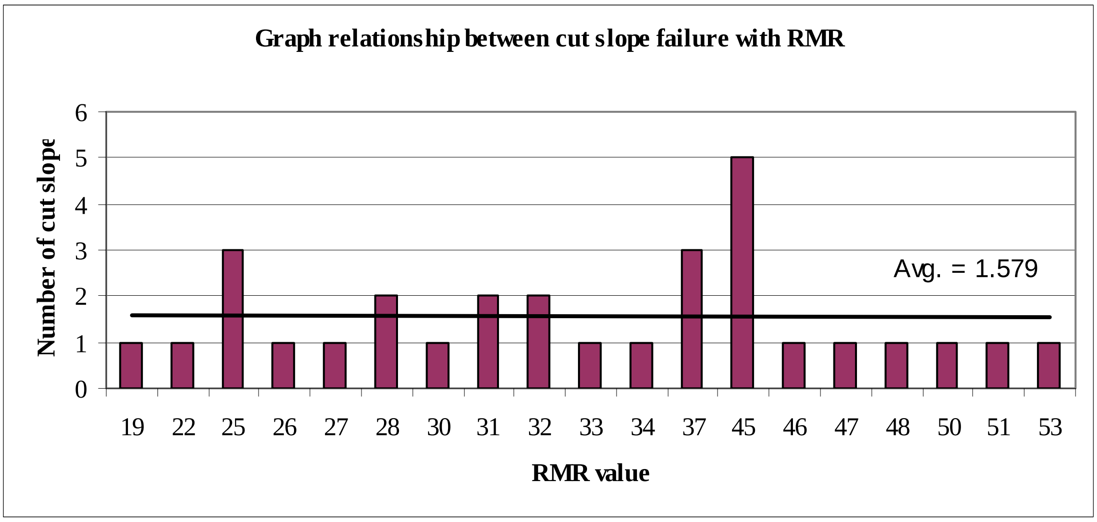


Figure 38 Graph relationships between cut slope failures and RMR rating

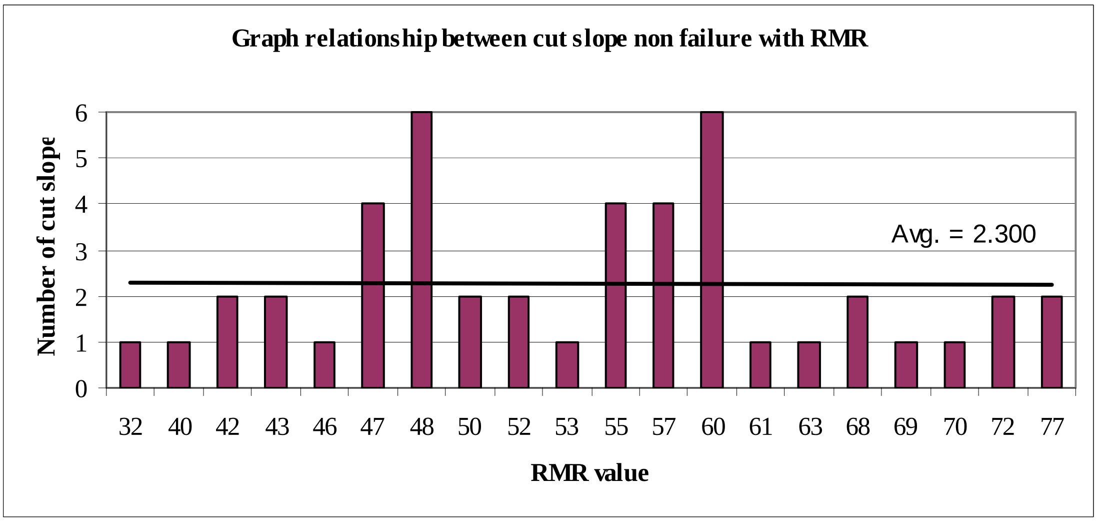


Figure 39 Graph relationships between cut slope non failures and RMR rating

Fig 40 shows normal distribution curve RMR value classified by slope condition. Fig 41 shows cumulative frequency of RMR value classified by slope condition. Fig 42 shows landslide potential classified by RMR value. These could assign the numerical weight for the RMR factor influencing the landslide in Phuket (Table 40).

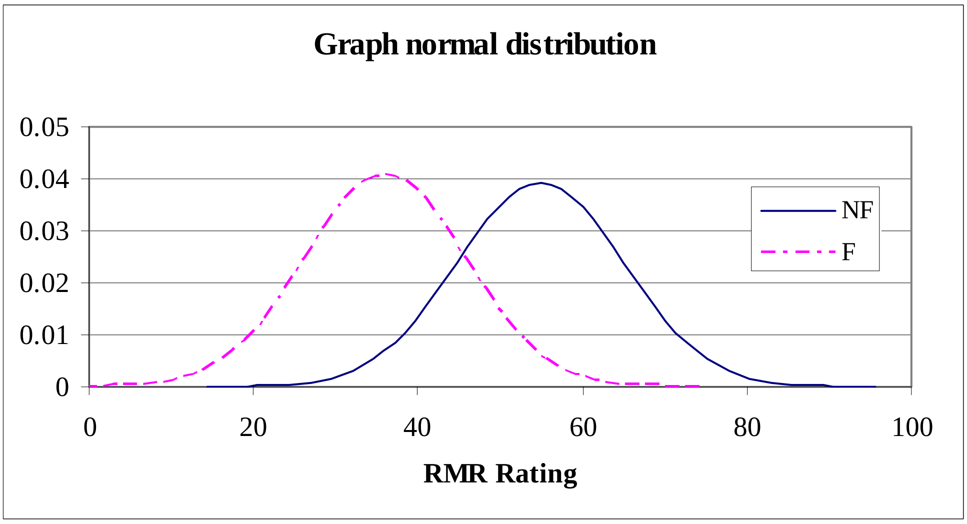


Figure 40 Normal distribution curve RMR value classified by slope condition

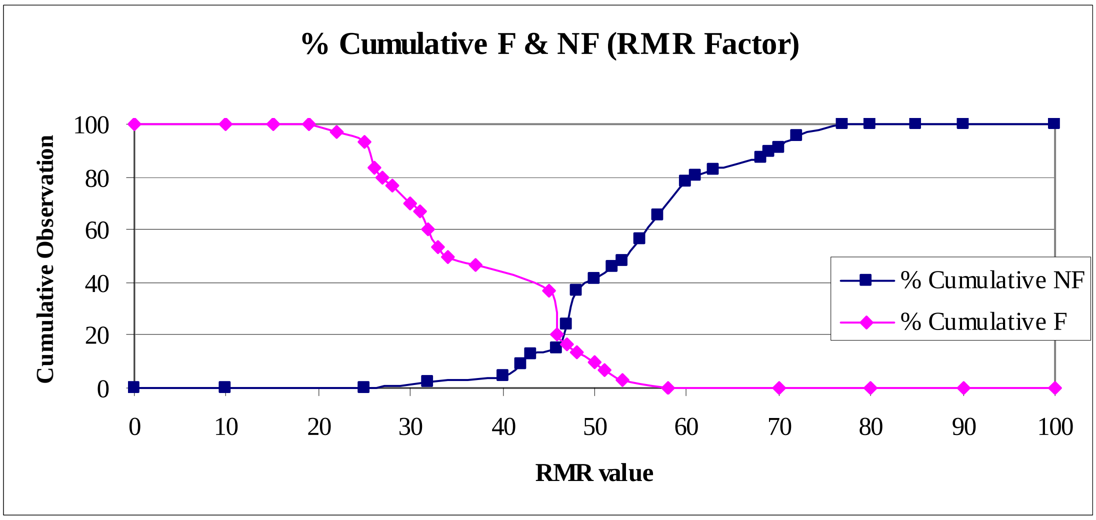


Figure 41 Cumulative frequency of RMR value classified by slope condition

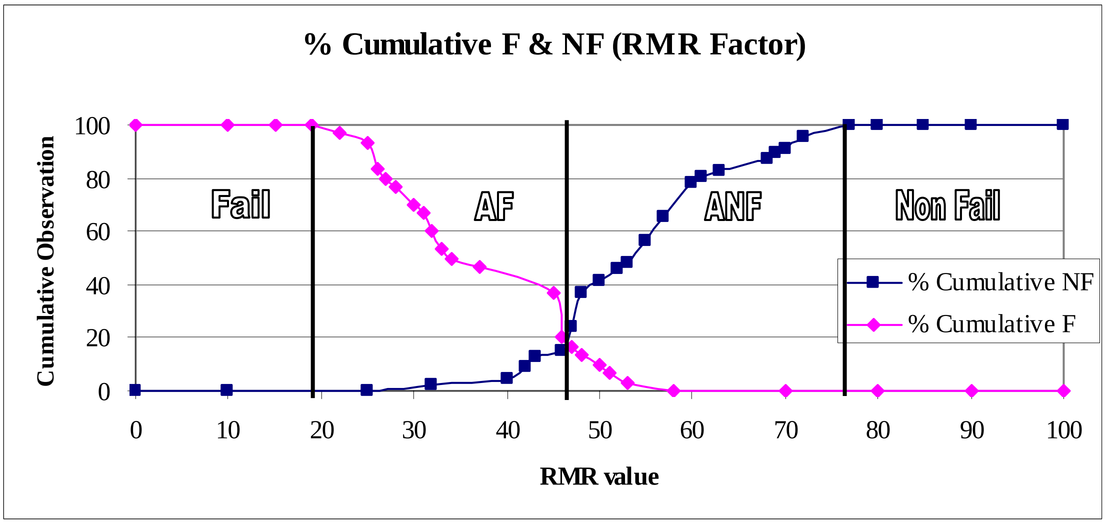


Figure 42 Landslide potential classified by RMR value

Table 40 The numerical weight assignment to the RMR factor influencing the landslide in Phuket.

Parameter	Weight Value		Rating Value		
	Parameter	Sub-parameter	Description	Landslide potential	Rating
RMR	5		A. 0 - 19 B. 19 - 46 C. 46 - 77 D. 77 - 100	F AF ANF NF	4 3 2 1

Processing Landslide Susceptibility and Hazard Map by Considering RMR Value

In this section, the processing of landslide susceptibility map determined the numerical rating of 7 related factors and RMR factor following weighting factor method (Table 40). The weight-rating values of each parameter determined in each 25x25 square meters grid cell, in which the summation of weight-rating values were classified range of score by landslide susceptibility classes (Table 33). The result are shown in Fig 43. Table 41 and Fig 44 show area of landslide classes considered by 7 related factors and RMR factor included.

This study performed comparison of landslide susceptibility map between RMR factor determination and non RMR factor determination in 1 year return period of rainfall intensity. The engineering soil properties factor and RMR factor were determined for landslide susceptibility factor because they are new factor in weighing factor method. Comparison of landslide susceptibility map between RMR factor determination and non RMR factor determination in 1 year return period of rainfall intensity is shown in Fig 45. The landslide susceptibility map for non RMR factor determination has higher landslide susceptibility in flat area than the landslide susceptibility map for engineering soil properties factor and RMR factor determination. Fig 46 shows comparison of landslide classes between considered by 7 related factors and considered by including 7 related factors and RMR factor which show the result of landslide high potential class in case RMR factor included had more area than no RMR factor included. So, the RMR factor was important factor to determine landslide susceptibility map.

Fig 47 (a) to (e) shows the results of processing of landslide hazard map considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by half of range between 25 to 120 which was 73 score. Fig 48 shows landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors and RMR factor included. Predicted landslide hazard area for 5 return periods of rainfall considered 7 related factors and RMR factor as shown in Table 41 and Fig 44. The plan area of landslide hazard was 2.20%, 4.79%, 10.01%, 11.10% and 13.30% for 1, 5, 20, 50 and 100 years return period of rainfall respectively in which the plan area of landslide hazard for 1 year return period overlap with plan area of landslide hazard for 5, 20, 50 and 100 year return period.

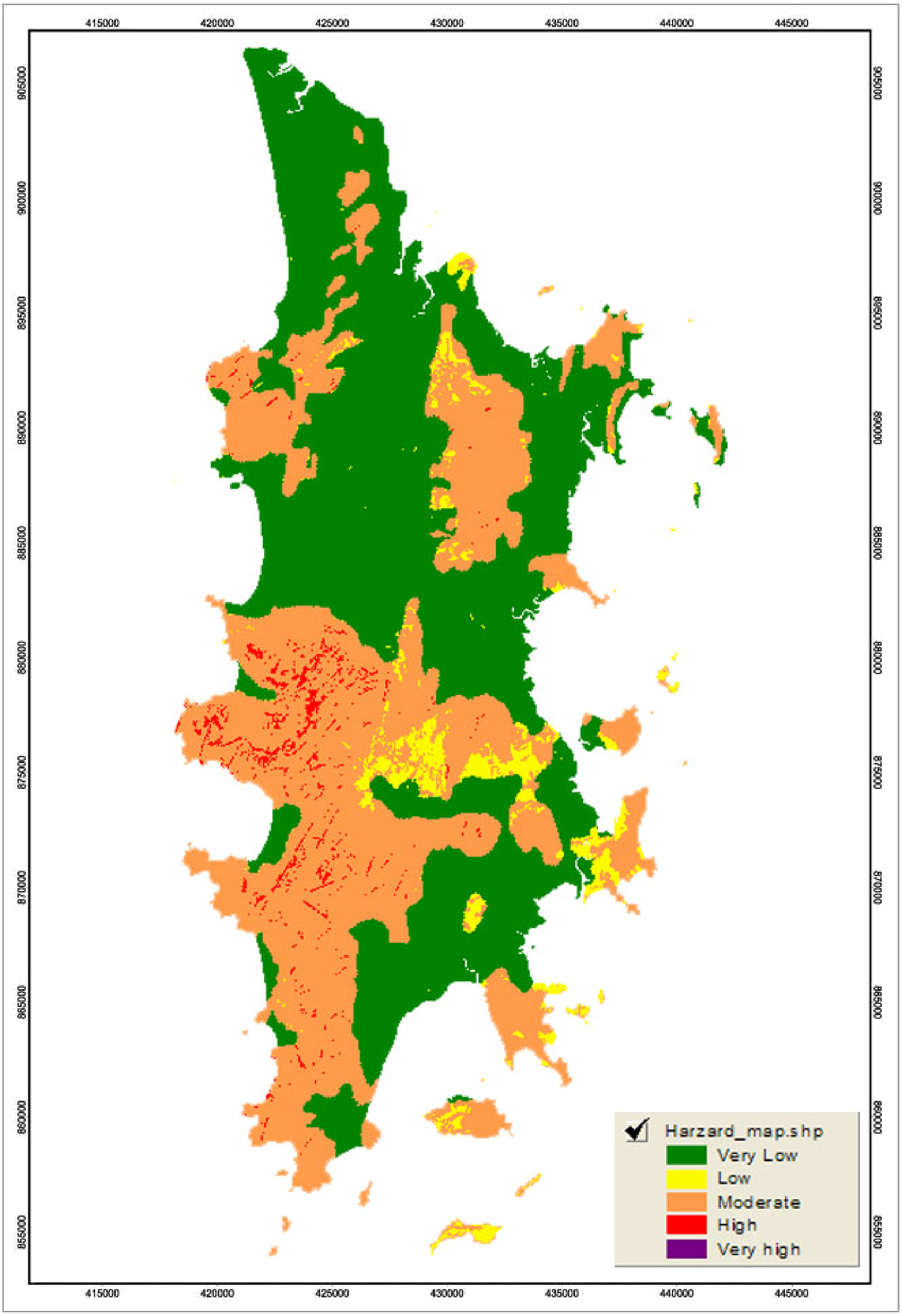


Figure 43 Landslide susceptibility map by considering 7 related factors and RMR factor

Table 41 Area of landslide classes considered by including 7 related factors and RMR factor

Score	Landslide Susceptibility Classes	pixel	Area (km^2)	%
101-120	Very high potential	0	0.00	0.00
82-101	High potential	19,330	12.08	2.20
63-82	Moderate potential	374,654	234.16	42.65
44-63	Low potential	46,554	29.10	5.30
25-44	Very low potential	437,879	273.67	49.85
	Sum	878,417	549	100.00

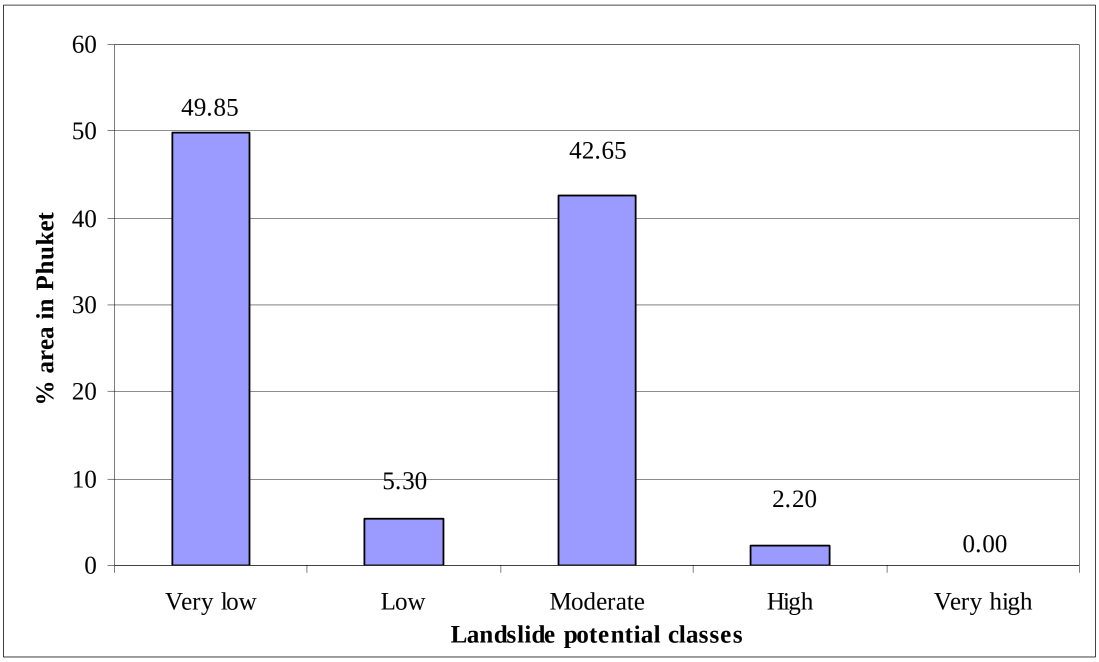
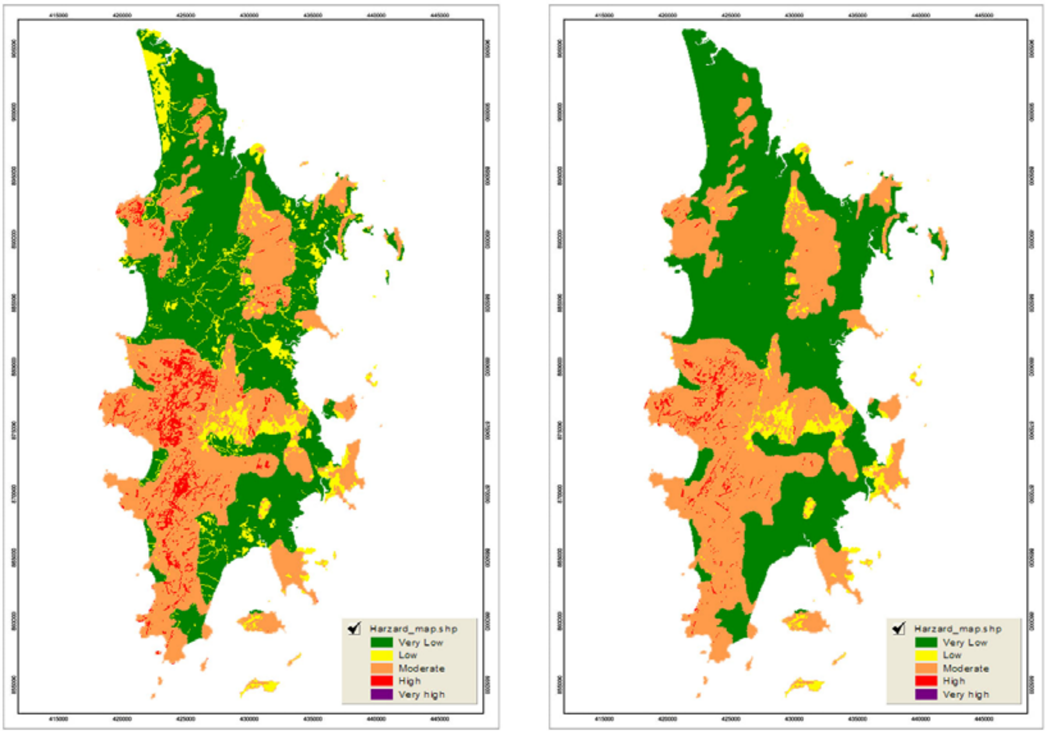


Figure 44 Area of landslide classes considered by including 7 related factors and RMR factor



(a) 7 factors (b) 7 factors and RMR factor

Figure 45 Comparison between the landslide susceptibility map by considering 7 related factors and considered by including 7 related factors and RMR factor

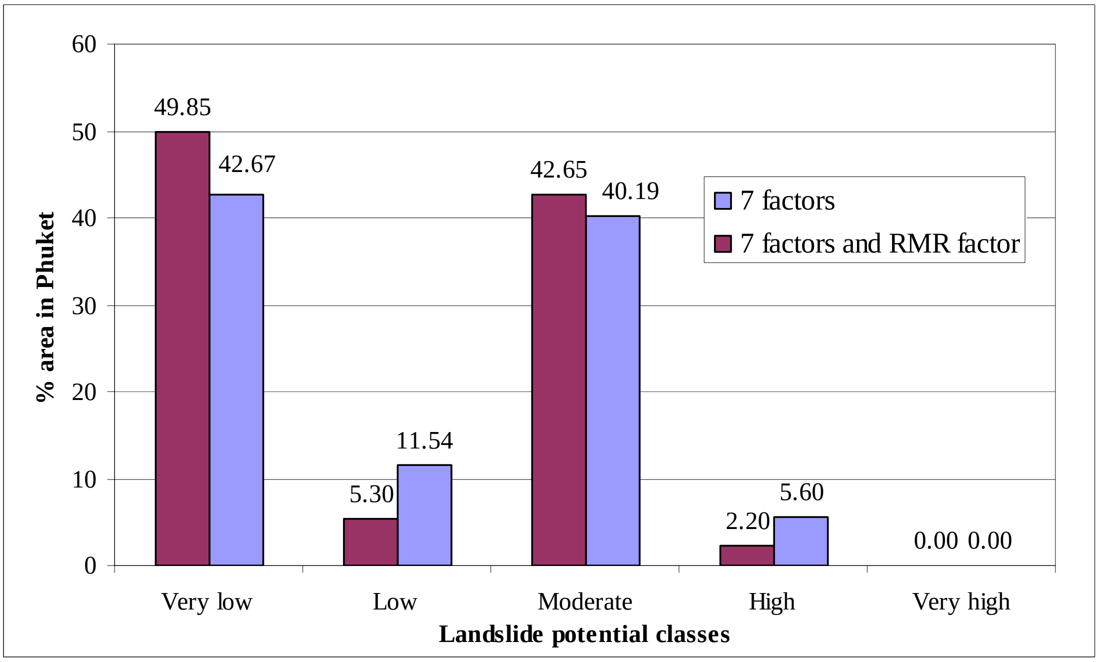
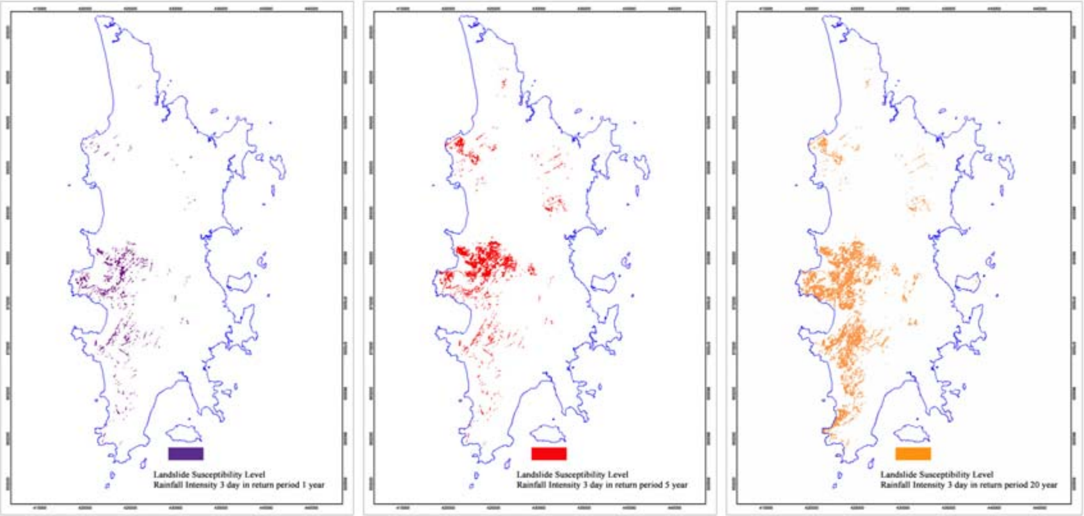
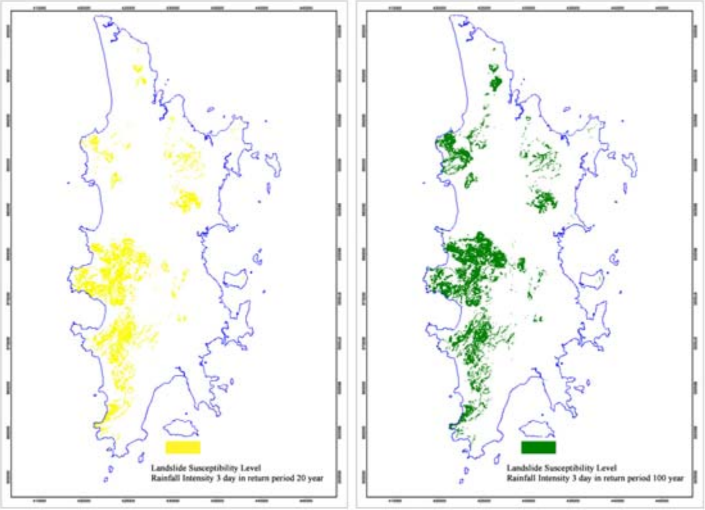


Figure 46 Comparison of landslide classes between considered by 7 related factors and considered by including 7 related factors and RMR factor



(a) 1 year (b) 5 years (c) 20 years



(d) 50 years (e) 100 years

Figure 47 The landslide hazard map in Phuket shown by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (RMR factor Included)

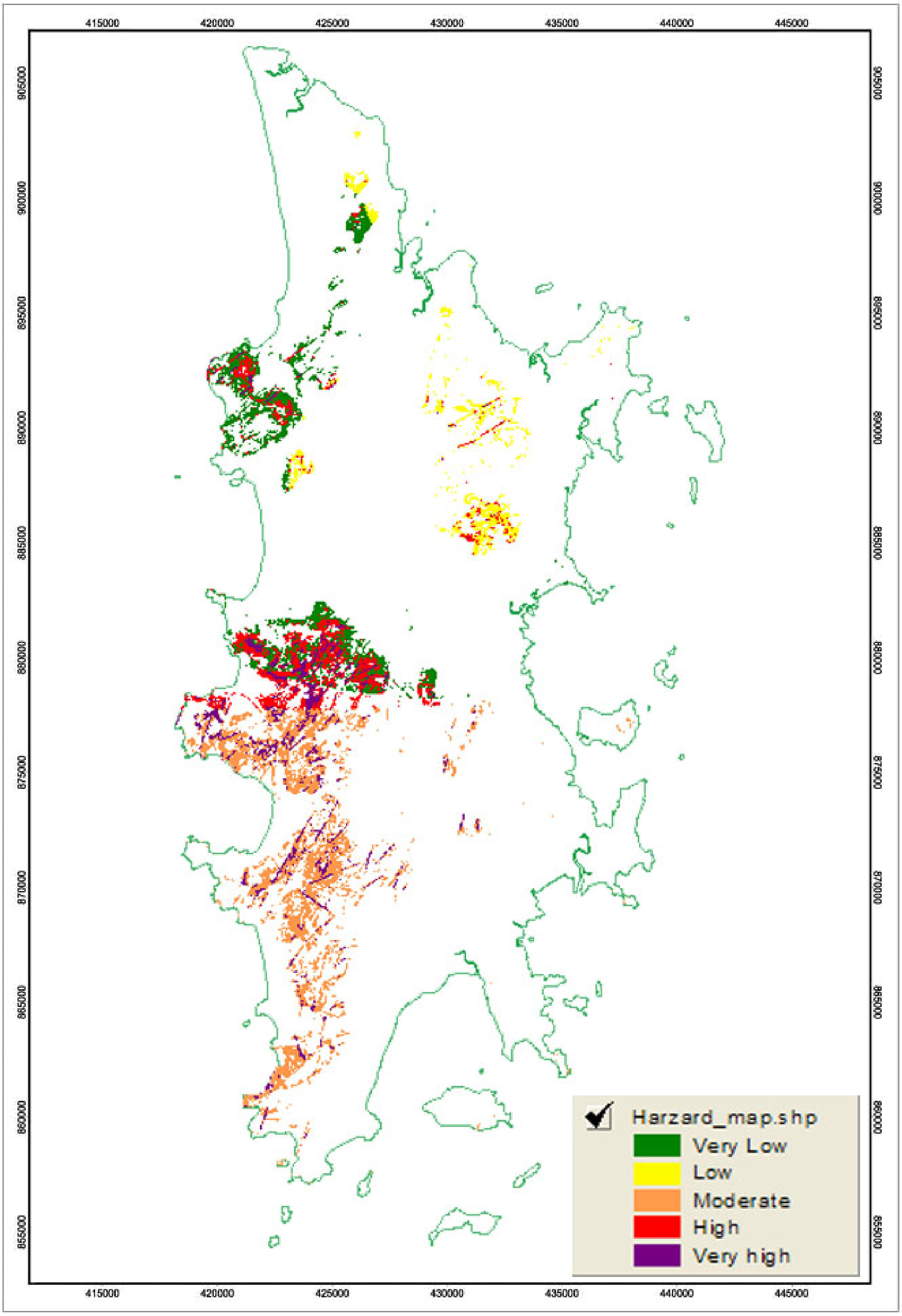


Figure 48 The landslide hazard map in Phuket by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (RMR factor Included)

Table 42 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and RMR factor

Return period of rainfall	Landslide classify	pixel	Area (km^2)	%
001	Fail	19,330	12.08	2.20
	No fail	859,087	536.93	97.80
005	Fail	42,094	26.31	4.79
	No fail	836,323	522.70	95.21
020	Fail	87,949	54.97	10.01
	No fail	790,468	494.04	89.99
050	Fail	97,544	60.97	11.10
	No fail	780,873	488.05	88.90
100	Fail	116,870	73.04	13.30
	No fail	761,547	475.97	86.70

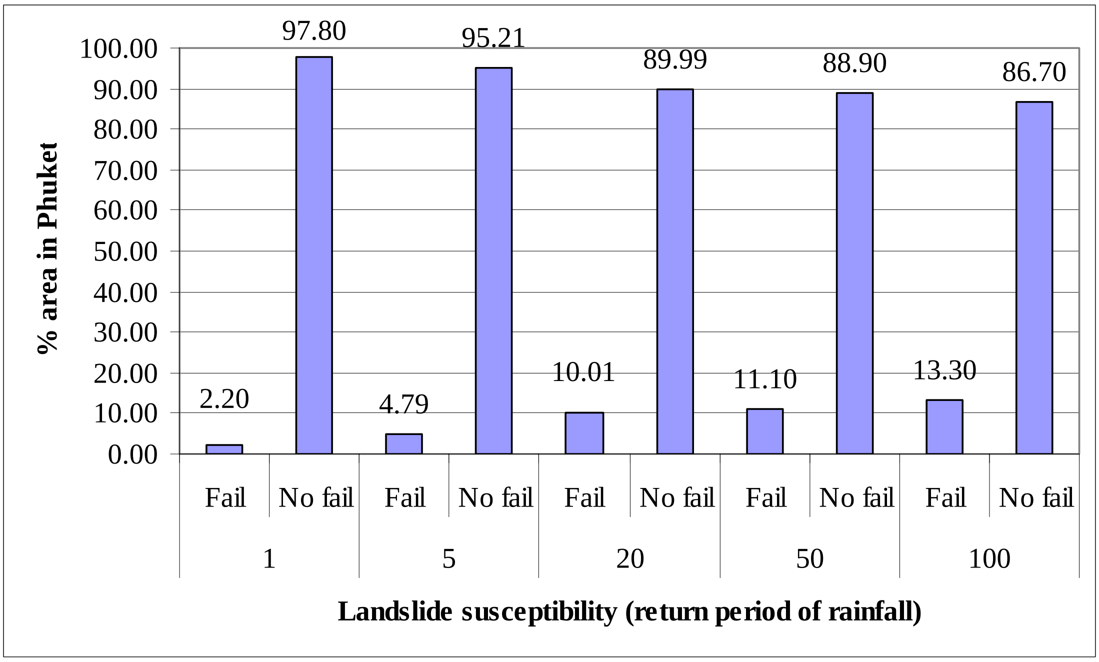
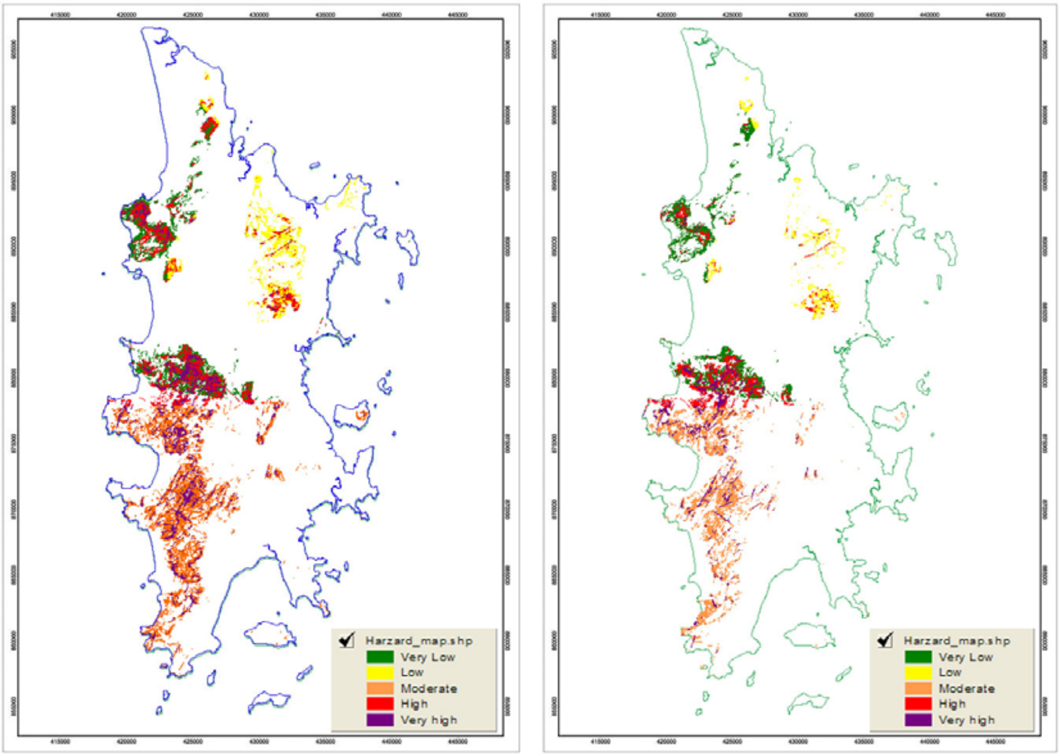


Figure 49 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and RMR factor



(a) 7 factors

(b) 7 factors and RMR factor

Figure 50 Comparison between the landslide hazard map by considering 7 related factors and considered by including 7 related factors and RMR factor

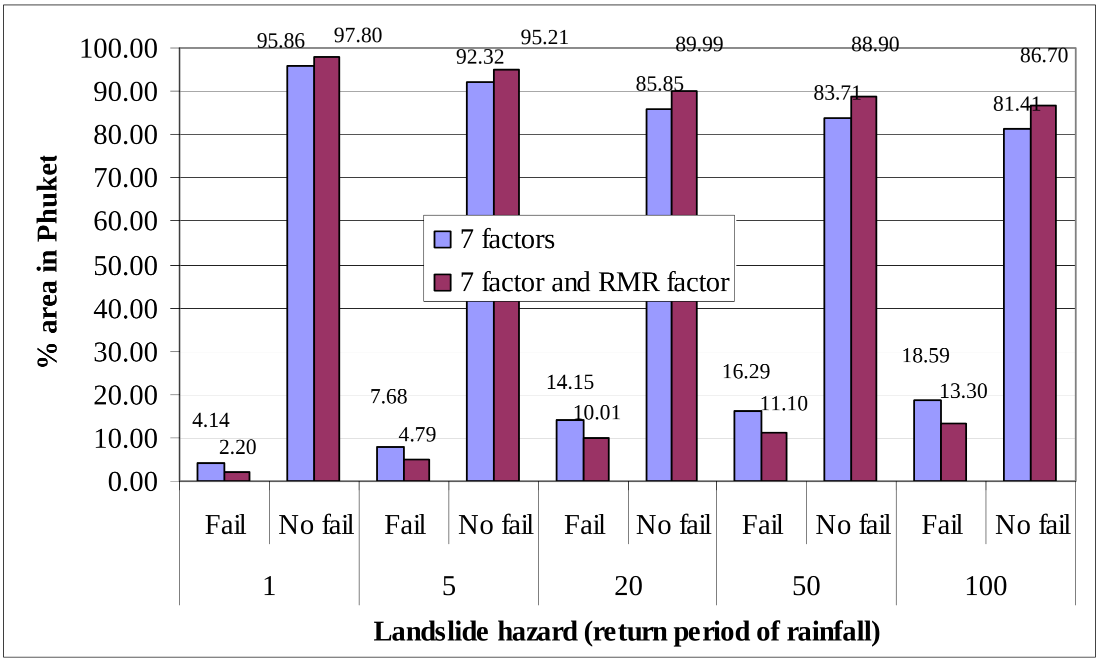


Figure 51 Comparison of landslide hazard between considered by 7 related factors and considered by including 7 related factors and RMR factor

Weighting Factor Analysis Including SMR Value

Appendix table 2 shows SMR rating estimation from field investigation data. Table 43 shows example of SMR estimation from field investigation. Table 44 shows average slope mass rating classified by rock type and watershed.

Table 43 Example of SMR estimation PK06

	Direction	Dip	F1	F2	F3	F4	RMR	SMR
Slope	278	40						
Bedding	324	40	0.15	0.85	-25	0	27	23.81
J1	183	88	0.15	1	0	0	27	27.00
J2	73	69	0.15	1	0	0	27	27.00
J3	26	45	0.15	1	-6	0	27	26.10
J4	130	64	0.15	1	0	0	27	27.00
J5	215	18	0.15	0.15	-60	0	27	25.65

Table 44 Average slope mass rating classified by rock type

Rock type	BASIN	Number	Avg. SMR
CP	CHALONG BASIN	1	25.25
	LAEM NGA BASIN	4	40.06
	MUANG BASIN	9	50.75
G2	KAMALA BASIN	14	33.88
	KARON BASIN	1	60.00
	KATA BASIN	1	47.00
	KATA NOI BASIN	1	32.00
	MUANG BASIN	4	60.52
	PATONG BASIN	13	45.55
	THA MAPHRAO BASIN	1	59.10
	THALANG BASIN	2	54.00
	THUNG NUNG BASIN	2	56.00
G3	THUNG NUNG BASIN	3	47.00
	THALANG BASIN	3	57.00
G4	LAEM KHAEK BASIN	3	32.54
	MUANG BASIN	5	57.16
	NA KHALE BASIN	1	26.94
	PATONG BASIN	6	41.43
	SAPAM BASIN	2	60.90

Fig 52 shows relationship between failure of cut slope and SMR value. Fig 53 shows relationship between non-failure of cut slope and SMR value.

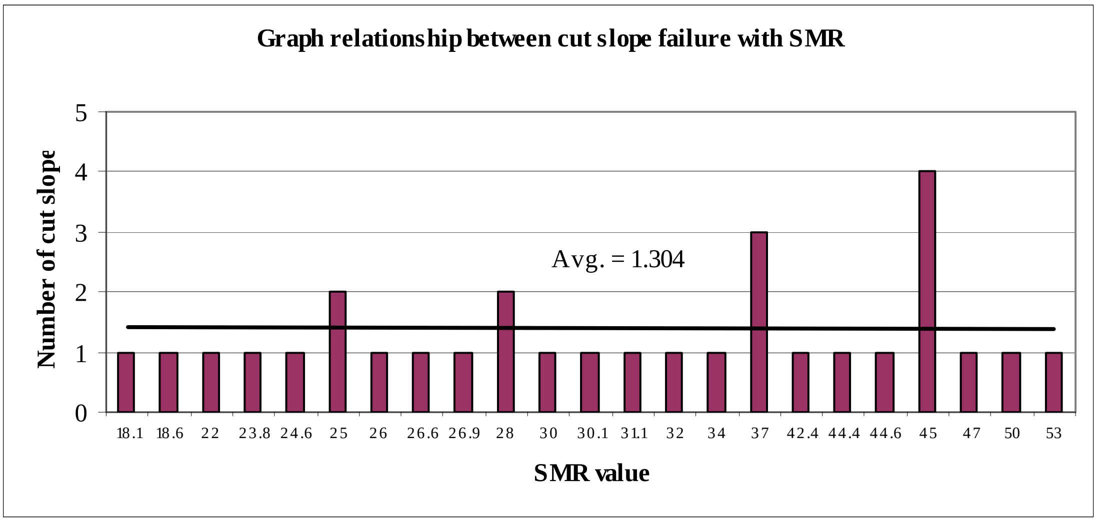


Figure 52 Graph relationships between cut slope failures and SMR rating

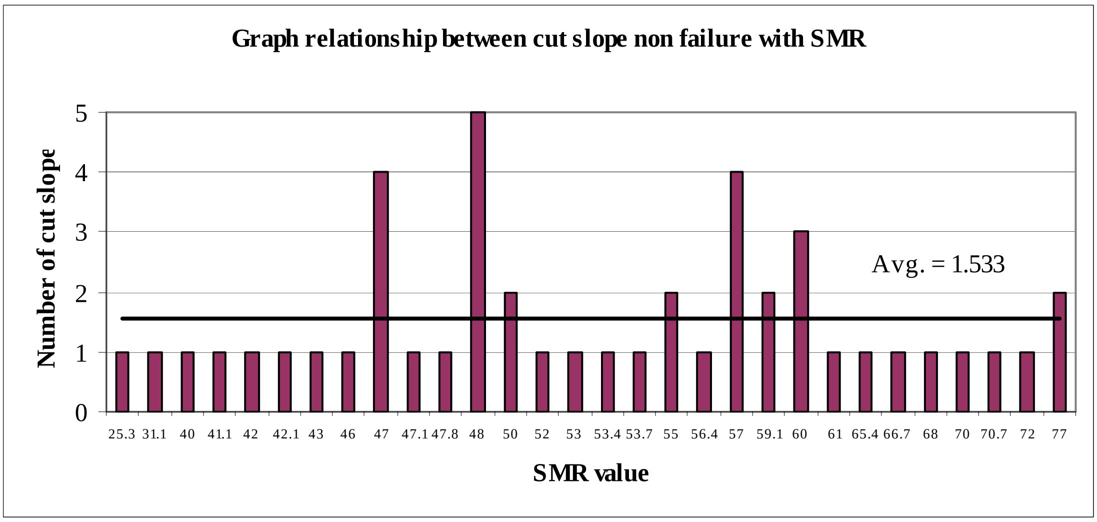


Figure 53 Graph relationships between cut slope non failures and SMR rating

Fig 54 shows normal distribution curve SMR value classified by slope condition. Fig 55 shows cumulative frequency of SMR value classified by slope condition. Fig 56 shows landslide potential classified by SMR value. These could assign the numerical weight for the SMR factor influencing the landslide in Phuket (Table 45).

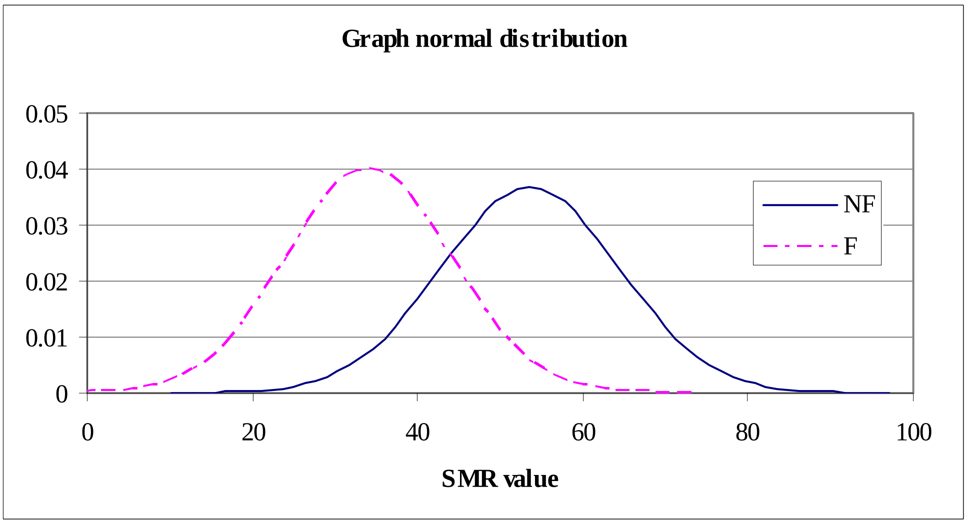


Figure 54 Normal distribution curve SMR value classified by slope condition.

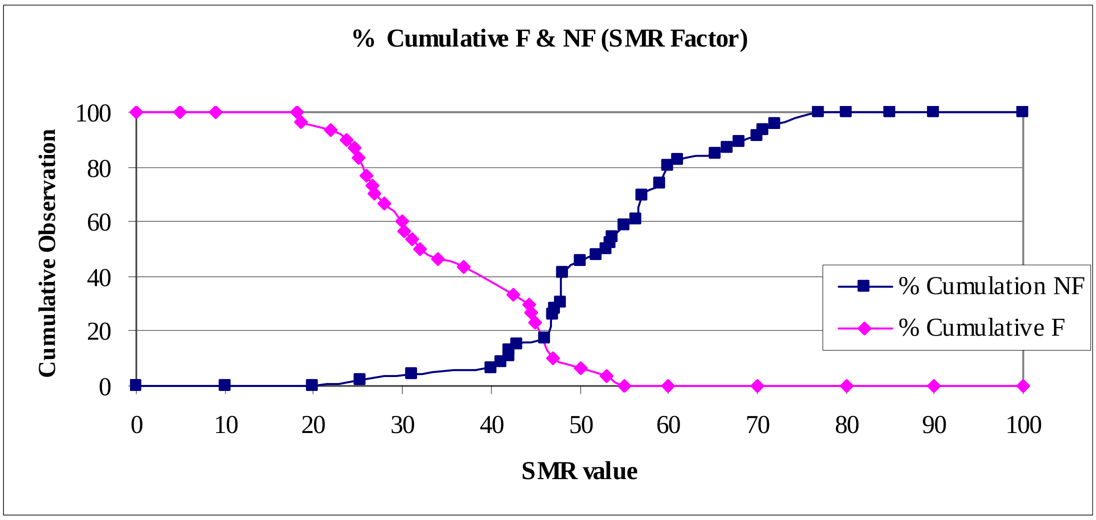


Figure 55 Cumulative frequency of SMR value classified by slope condition

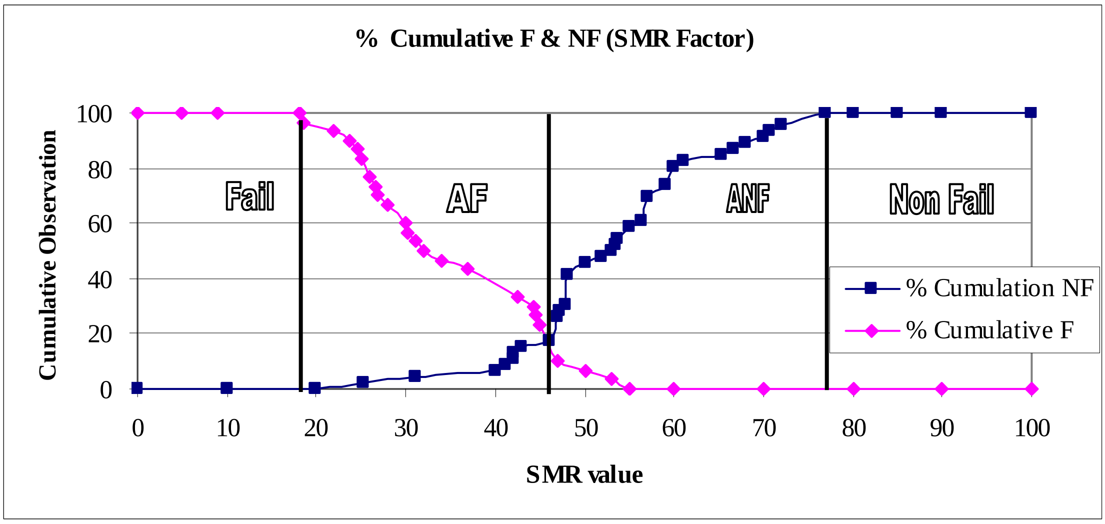


Figure 56 Landslide potential classified by SMR value

Table 45 The numerical weight assignment to the SMR factor influencing the landslide in Phuket

Parameter	Weight Value		Rating Value		
	Parameter	Sub-parameter	Description	Landslide potential	Rating
SMR	5		A. 0 - 19 B. 19 - 46 C. 46 - 77 D. 77 - 100	F AF ANF NF	4 3 2 1

Processing Landslide Susceptibility and Hazard Map by Considering SMR Value

In this section, the processing of landslide susceptibility map determined the numerical rating of 7 related factors and SMR factor following weighting factor method (Table 45). The weight-rating values of each parameter determined in each 25x25 square meter grid cell, in which the summation of weight-rating values were classified range of score by landslide susceptibility classes (Table 33). The result are shown in Fig 57. Table 46 and Fig 58 show area of landslide classes considered by 7 related factors and SMR factor included.

This study performed comparison of landslide susceptibility map between SMR factor determination and non SMR factor determination in 1 year return period of rainfall intensity. The engineering soil properties factor and SMR factor were determined for landslide susceptibility factor because they are new factor in weighing factor method. Comparison of landslide susceptibility map between SMR factor determination and non SMR factor determination in 1 year return period of rainfall intensity is shown in Fig 59. The landslide susceptibility map for non SMR factor determination has higher landslide susceptibility in flat area than the landslide susceptibility map for engineering soil properties factor and SMR factor determination. Fig 60 shows comparison of landslide classes between considered by 7 related factors and considered by including 7 related factors and SMR factor which show the result of landslide high potential class in case SMR factor included had more area than no SMR factor included. So, the SMR factor was important factor to determine landslide susceptibility map.

Fig 61 (a) to (e) shows the results of processing of landslide hazard map considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by half of range between 25 to 120 which was 73 score. Fig 62 shows landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors and RMR factor included. Predicted landslide hazard area for 5 return period of rainfall considered 7 related factors and RMR factor are shown in Table 38 and Fig 63. The plan area of landslide hazard was 5.93%, 9.01%, 14.67%, 18.12% and 13.50% for 1, 5, 20, 50 and 100 years return period of rainfall respectively in which the plan area of landslide hazard for 1 year return period overlap with plan area of landslide hazard for 5, 20, 50 and 100 year return period.

Fig 64 and Fig 65 show comparison between the landslide hazard map which considered only 7 related factors, 7 related factors and RMR factor included and 7 related factors and SMR factor included. The results were slightly different.

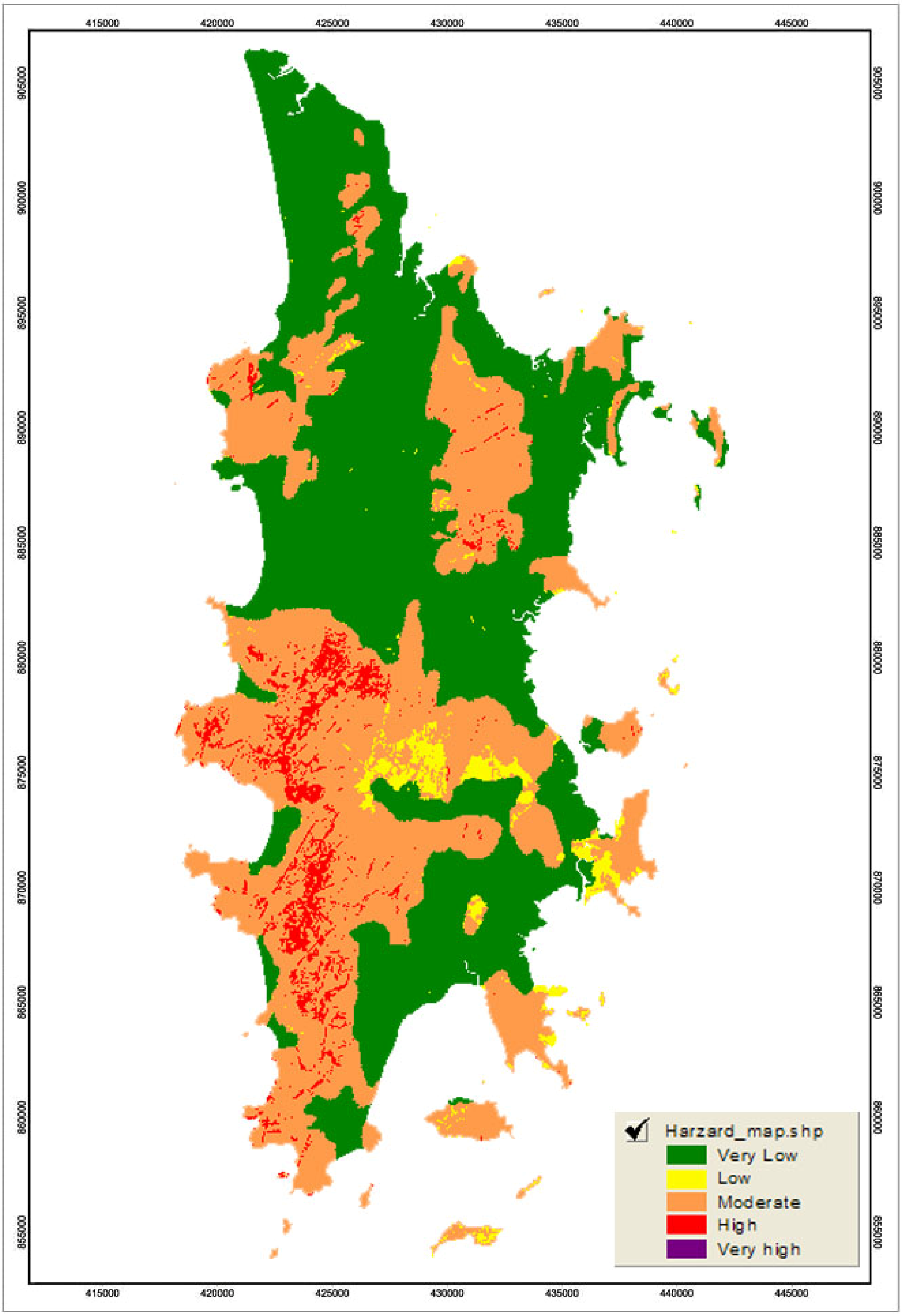


Figure 57 Landslide susceptibility map by considering 7 related factors and SMR factor

Table 46 Area of landslide classes considered by including 7 related factors and SMR factor

Score	Landslide Susceptibility Classes	pixel	Area (km^2)	%
101-120	Very high potential	0	0.00	0.00
82-101	High potential	51,965	32.48	5.92
63-82	Moderate potential	355,369	222.11	40.46
44-63	Low potential	33,330	20.83	3.79
25-44	Very low potential	437,753	273.60	49.83
	Sum	878,417	549	100.00

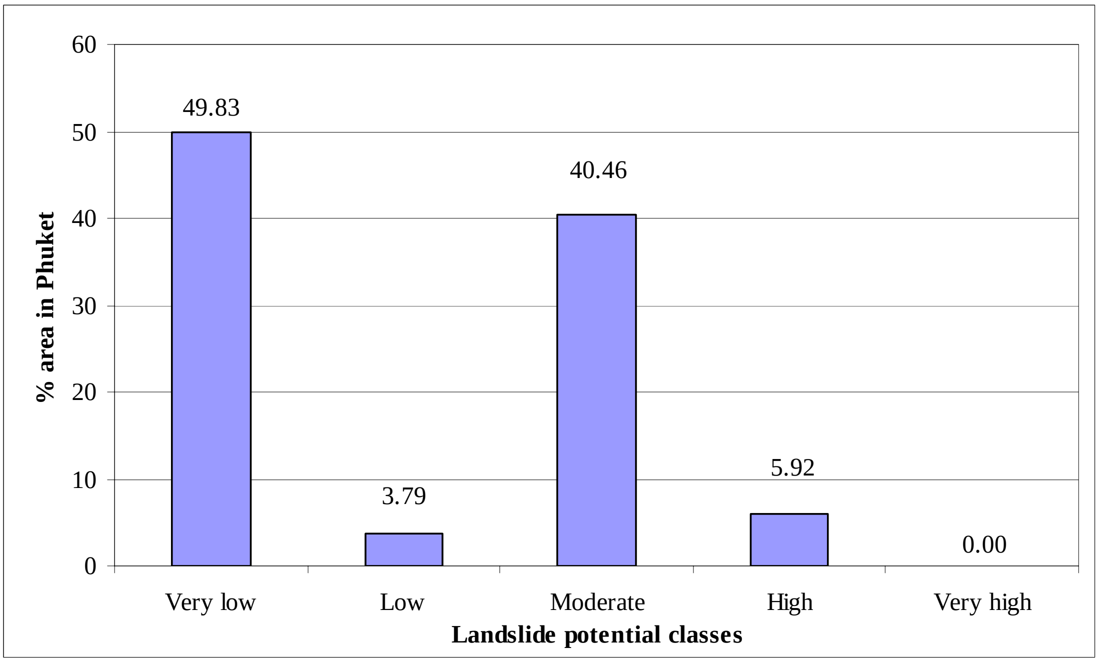
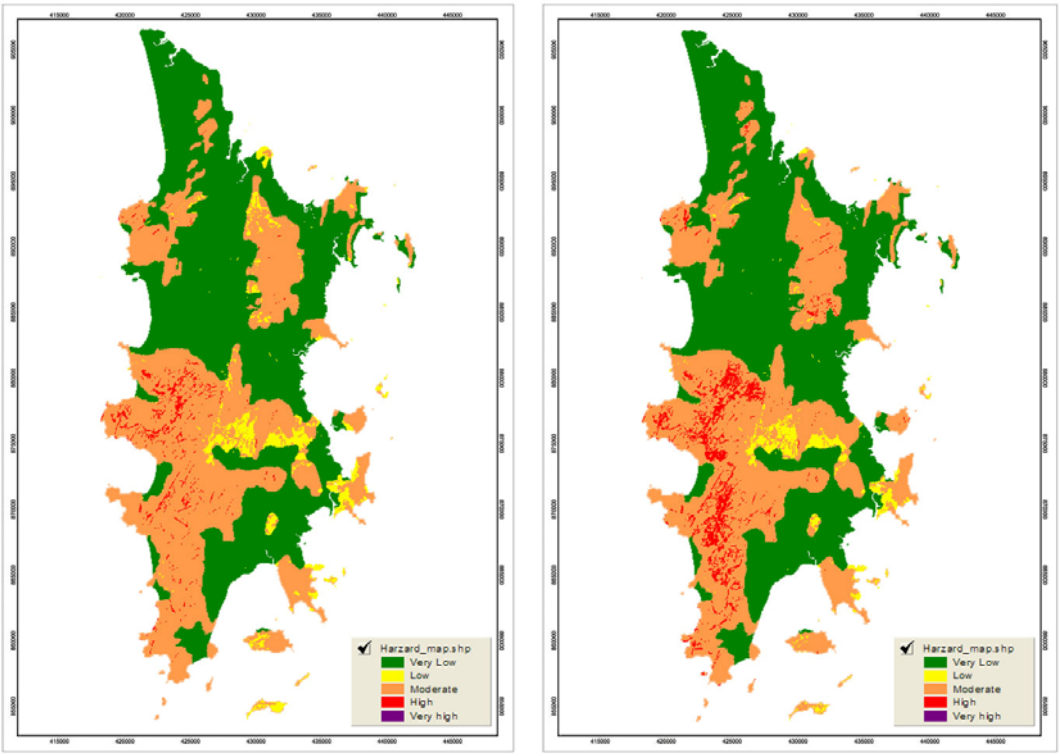


Figure 58 Area of landslide classes considered by including 7 related factors and SMR factor



(a) 7 factors and RMR factor (b) 7 factors and SMR factor

Figure 59 Comparison between the landslide susceptibility map

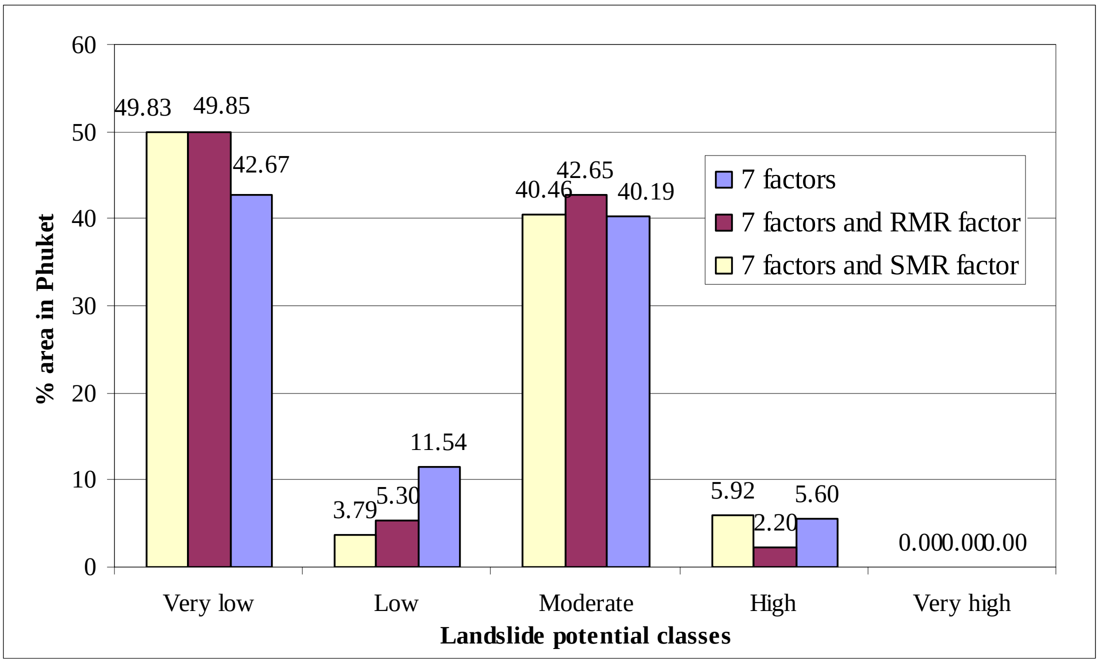
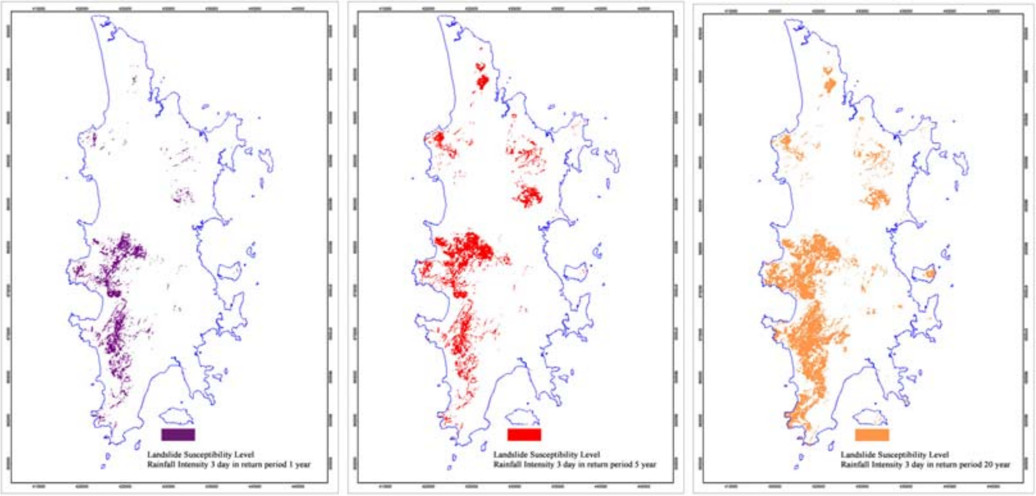
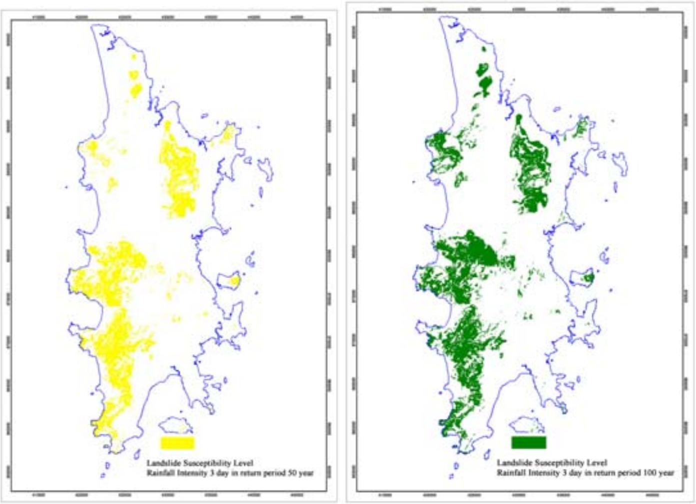


Figure 60 Comparison of landslide classes



(a) 1 year (b) 5 years (c) 20 years



(d) 50 years (e) 100 years

Figure 61 The landslide hazard map in Phuket shown by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (SMR factor included)

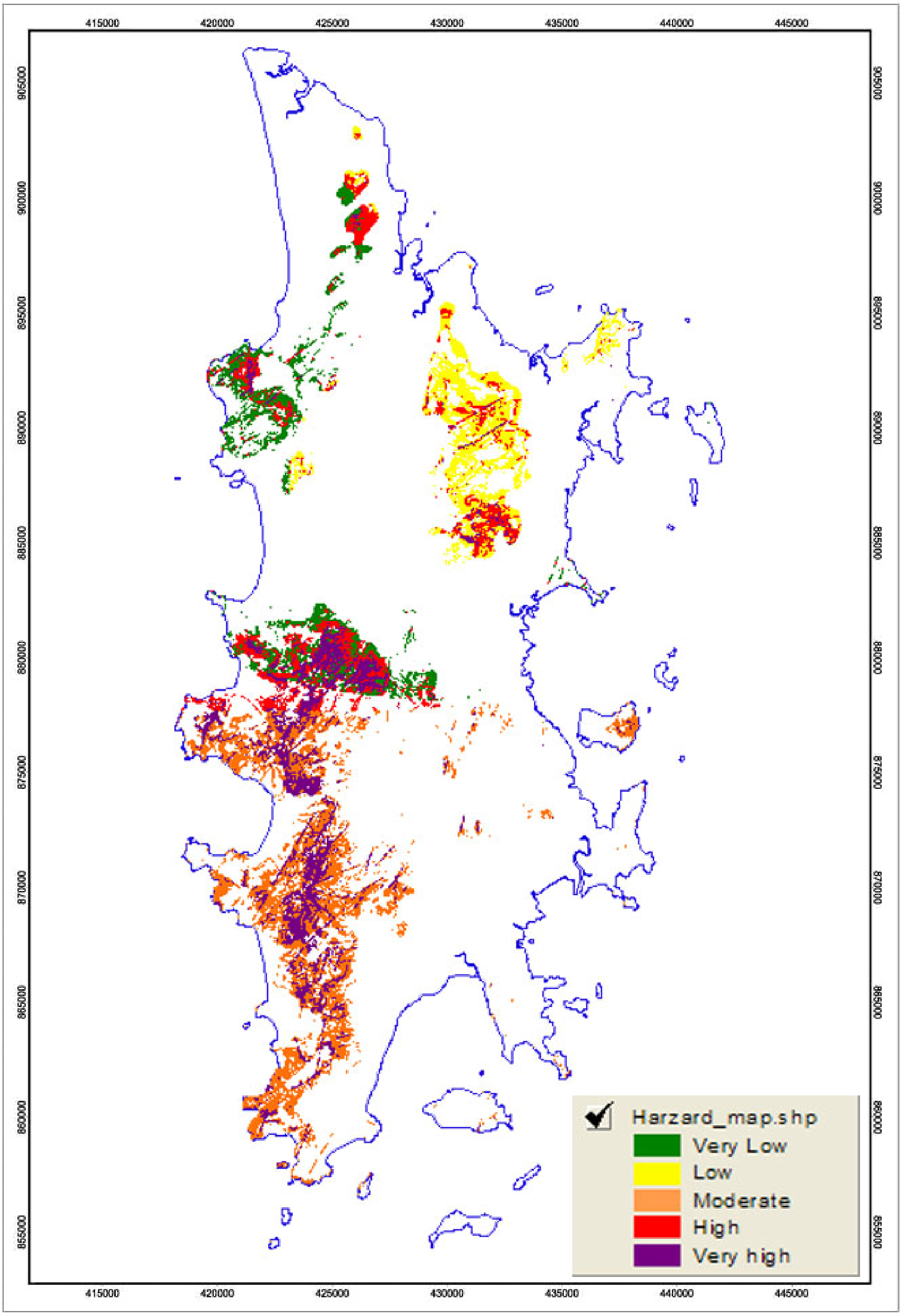


Figure 62 The landslide hazard map in Phuket by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (SMR factor included)

Table 47 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and SMR factor

Return period of rainfall	Landslide classify	pixel	Area (km^2)	%
1	Fail	52,061	32.54	5.93
	No fail	826,356	516.47	94.07
5	Fail	79,189	49.49	9.01
	No fail	799,228	499.52	90.99
20	Fail	128,843	80.53	14.67
	No fail	749,574	468.48	85.33
50	Fail	159,130	99.46	18.12
	No fail	719,287	449.55	81.88
100	Fail	118,602	74.13	13.50
	No fail	759,815	474.88	86.50

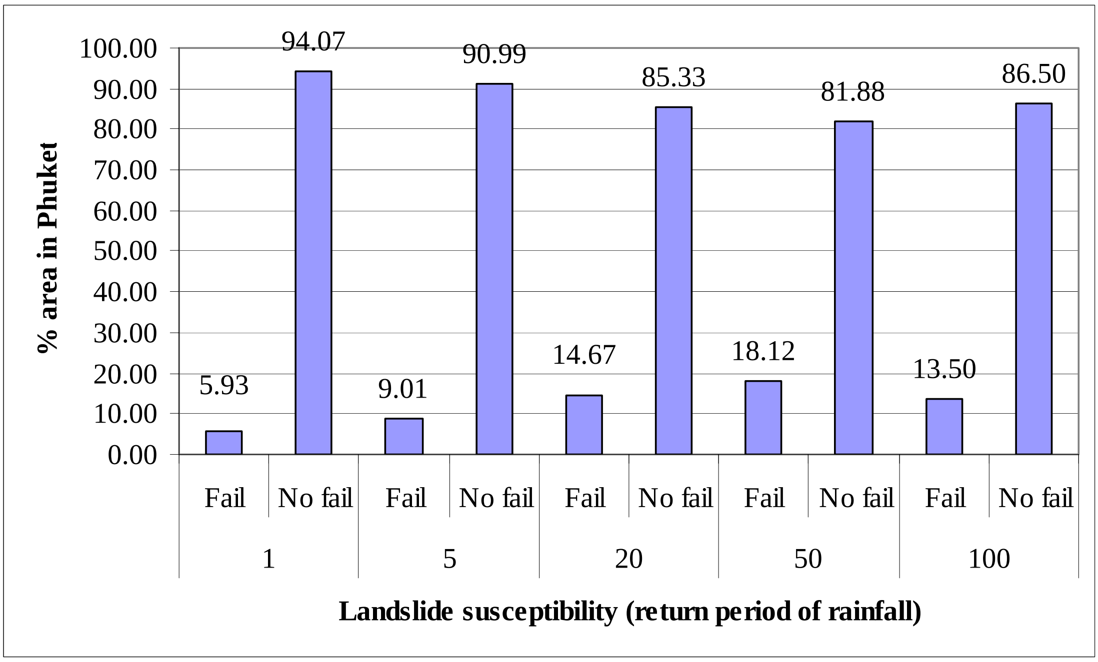
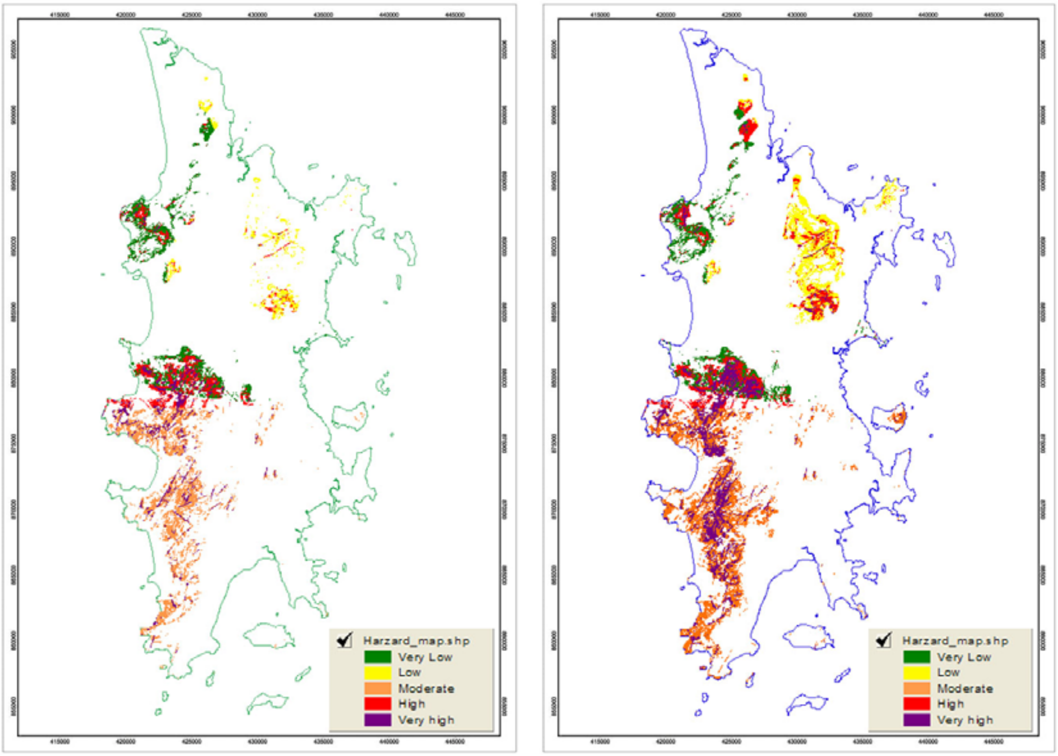


Figure 63 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and RMR factor



(a) 7 factors and RMR factor (b) 7 factors and SMR factor

Figure 64 Comparison between the landslide hazard map

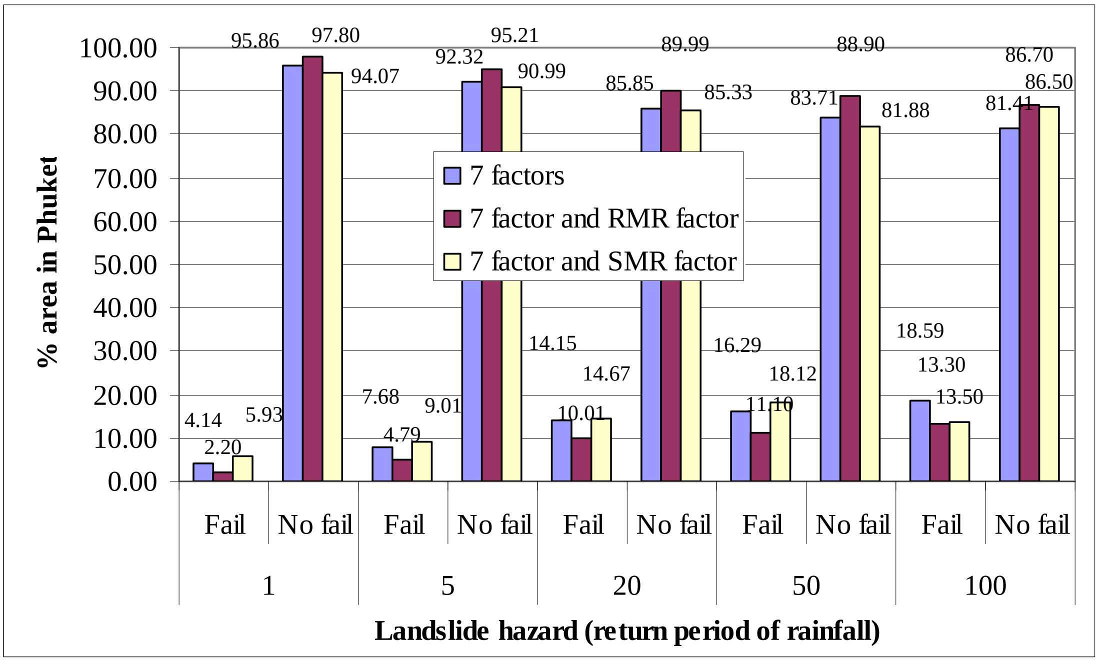


Figure 65 Comparison of landslide hazard

Collect Slope Condition Data from Field Investigation

Appendix table 2 shows slope condition data from field investigation. The slope condition was used for classification potential of cut slope failure.

Failure Verification (RMR included)

Fig 66 shows relationship between failure of cut slope and RMR factor. Fig 67 shows relationship between non failure of cut slope and RMR factor. Fig 68 shows normal distribution of total score considered 7 related factors and RMR factor to classify by slope condition.

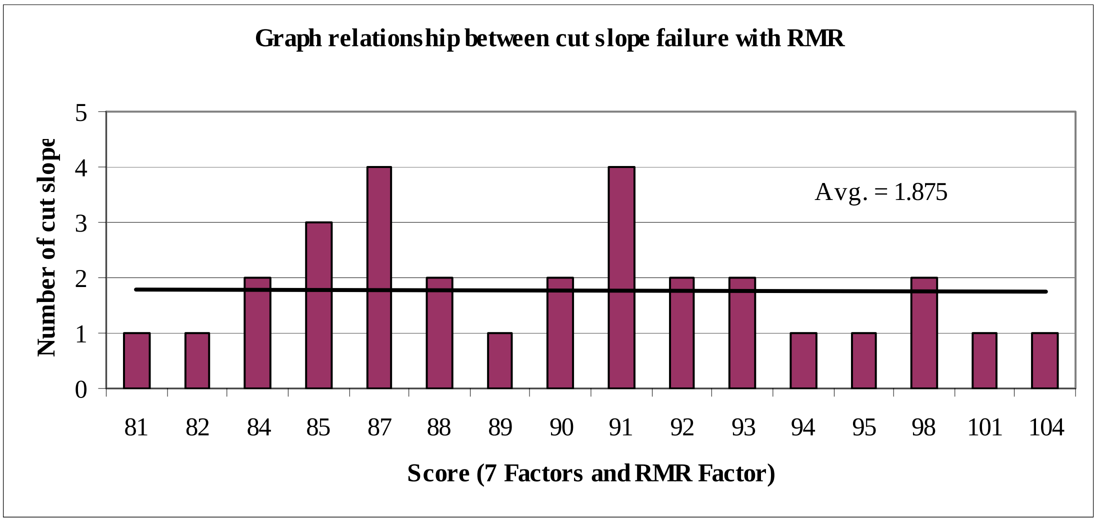


Figure 66 Graph relationships between failure of cut slope and RMR factor

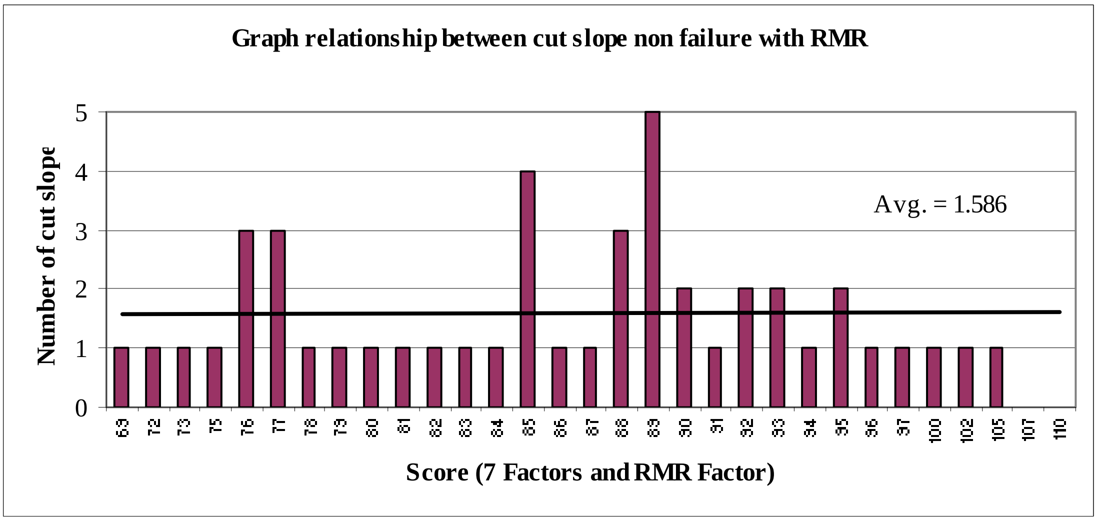


Figure 67 Graph Relationships between non failure of cut slope and RMR factor

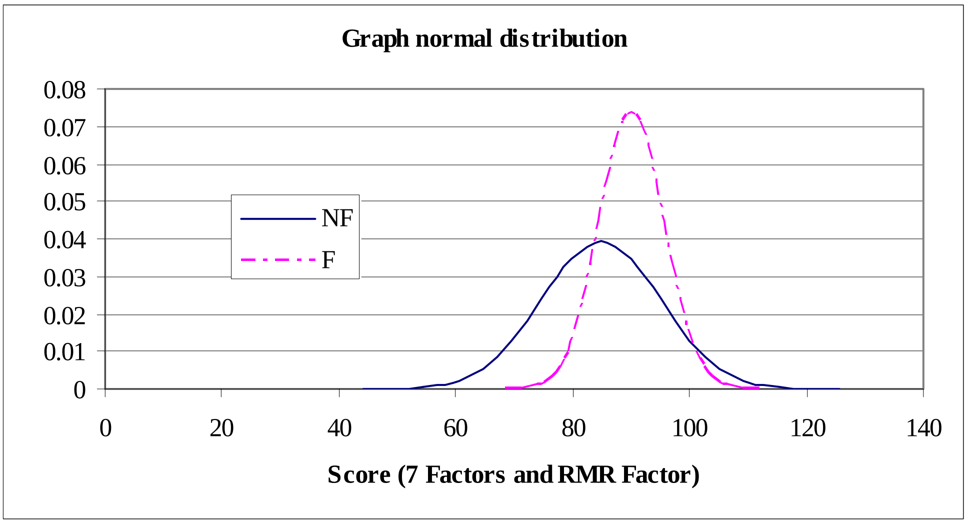


Figure 68 Normal distribution of total score (7 related factors and RMR factor) classified by slope condition

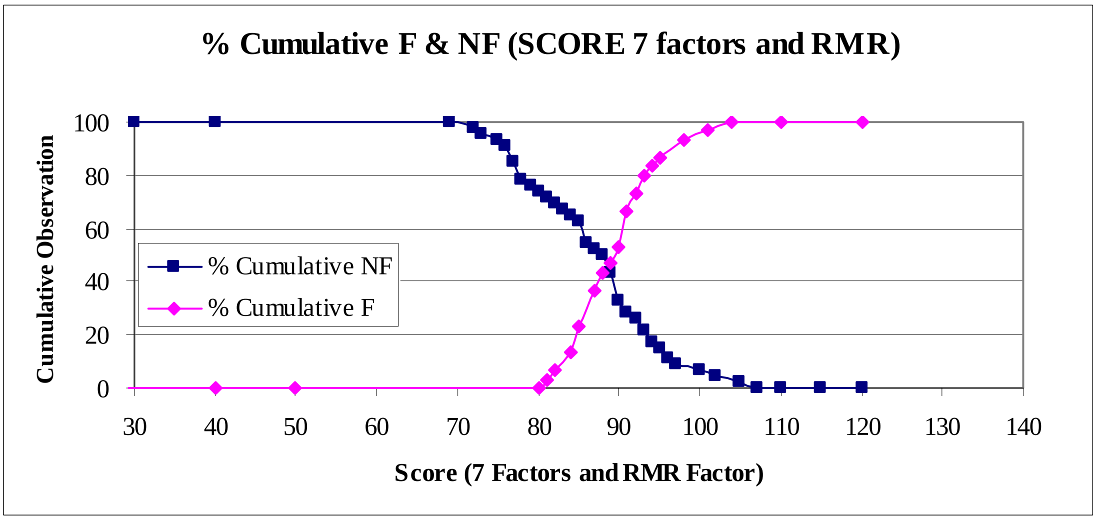


Figure 69 Cumulative frequency of total score (7 related factors and RMR factor) classified by slope condition

Fig 69 shows cumulative frequency of total score considered 7 related factors and RMR factor to classify by slope condition. Fig 70 shows cut slope failure potential classified by 7 related factors and RMR factor.

Table 48 shows the landslide potential and the range of total score considering RMR factor for all return periods of rainfall which considered from cumulative of failure and non-failure frequency (Fig 70).

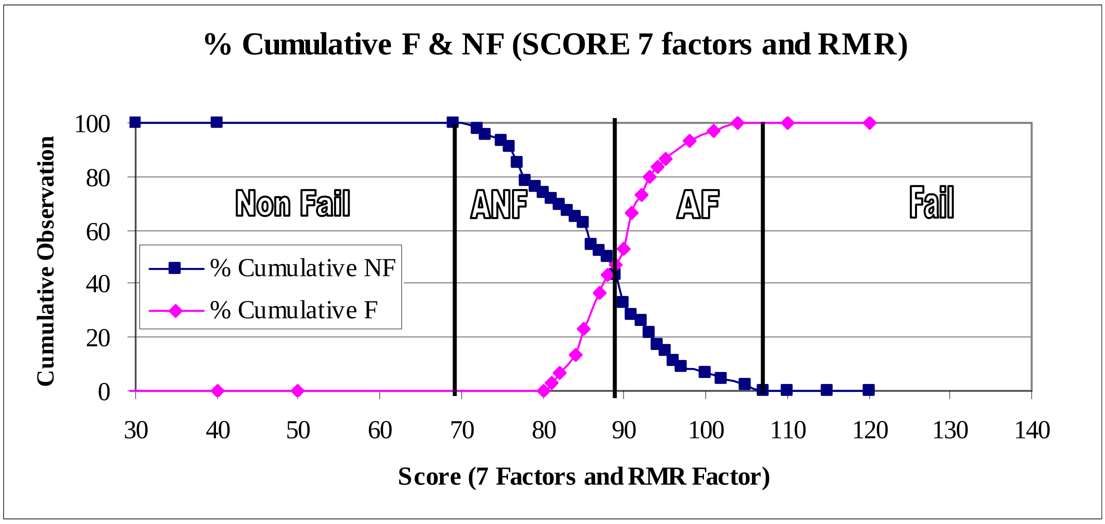


Figure 70 Cut slope failure potential classified by 7 related factors and RMR factor

Table 48 The landslide potential and the range of total score considering RMR factor for all return periods of rainfall

Cut slope failure classes	Range of score
Very high potential	107-140
High potential	89-107
Low potential	69-89
Very low potential	30-69

Processing Cut Slope Failure and Hazard Map by Considering RMR Factor Included

In this section, the processing of landslide hazard map due to cut slope determined the numerical rating of 7 related factors and RMR factor following weighting factor method (Table 40). The weight-rating values of each parameter determined in each 25x25 square meter grid cell, in which the summation of weight-rating values were classified range of score by cut slope failure classes (Table 48). The result are shown in Fig 71. Table 49 and Fig 72 show area of cut slope failure classes considered by 7 related factors and RMR factor included.

Fig 73 (a) to (e) shows the results of processing of landslide hazard map due to cut slope considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by cumulative of failure and non-failure frequency that was 89 score. Fig 73 shows landslide hazard map due to cut slope using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors and RMR factor included. Predicted landslide hazard area due to cut slope for 5 return period of rainfall considered 7 related factors and RMR factor shown in Table 50 and Fig 74. The plan area of landslide hazard due to cut slope was 0.71%, 2.03%, 4.44%, 5.01% and 7.06% for 1, 5, 20, 50 and 100 years return period of rainfall.

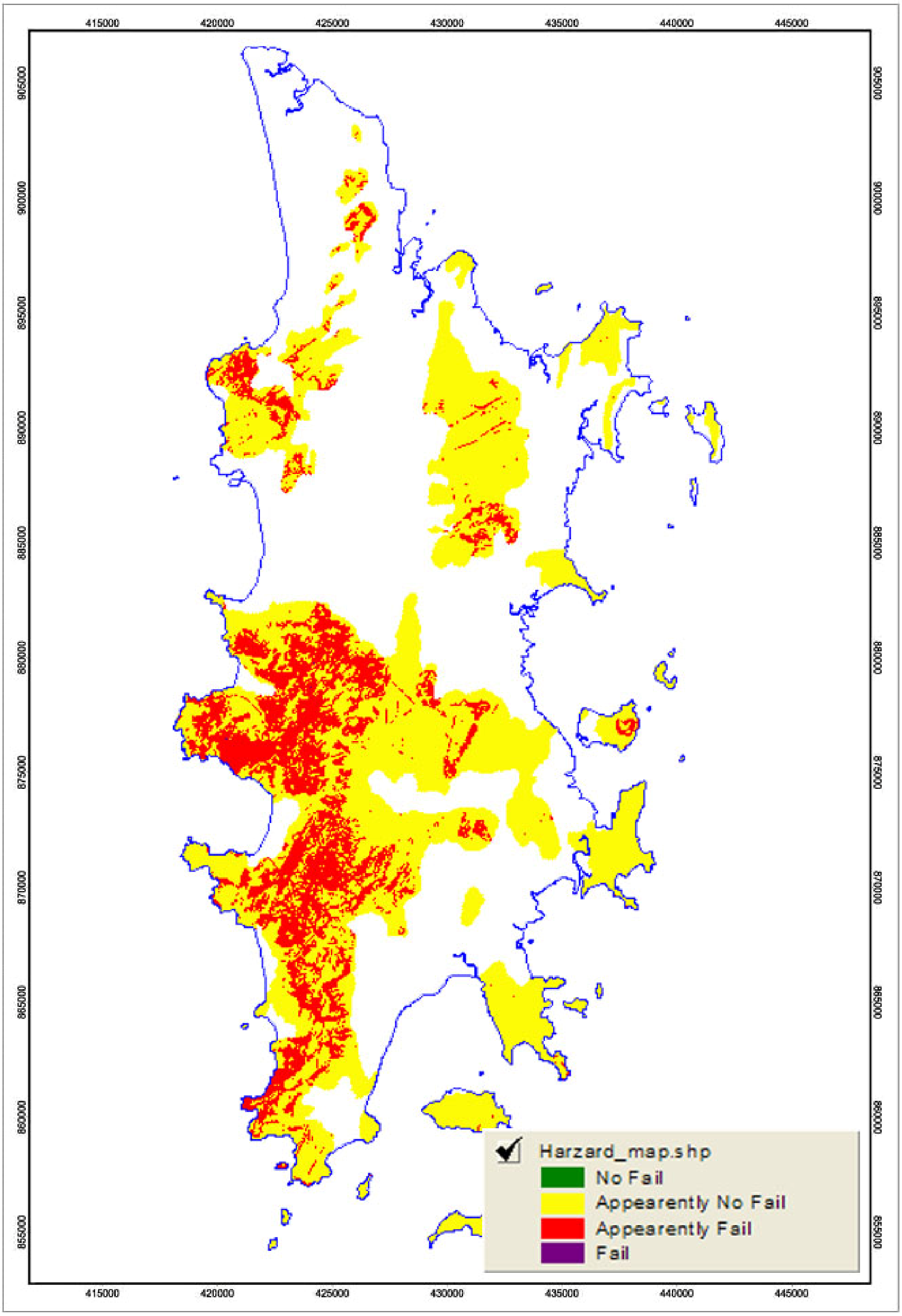


Figure 71 Area of failure cut slope classes considered by including 7 related factors and RMR factor

Table 49 Area of failure cut slope classes considered by including 7 related factors and RMR factor

Score	Failure cut slope Classes	pixel	Area (km^2)	%
96 - 118	Fail	121	0.08	0.01
74 - 96	Apparently fail	119,134	74.46	13.56
69 - 74	Apparently no fail	321,283	200.80	36.58
30 - 69	No fail	437,879	273.67	49.85
	Sum	878,417	549.01	100.00

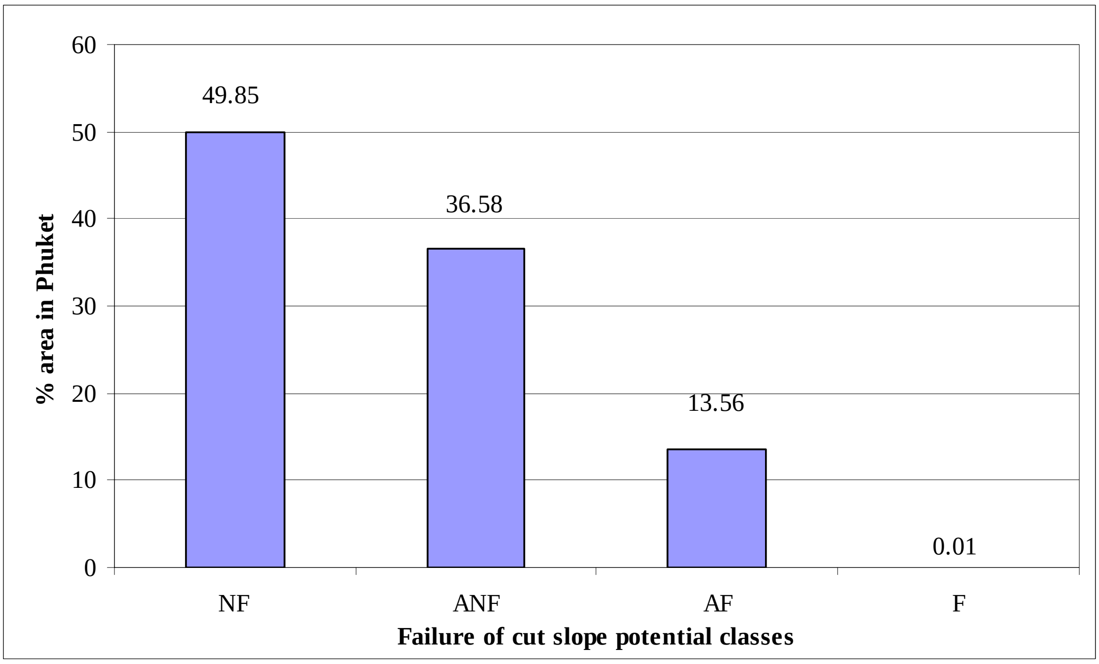
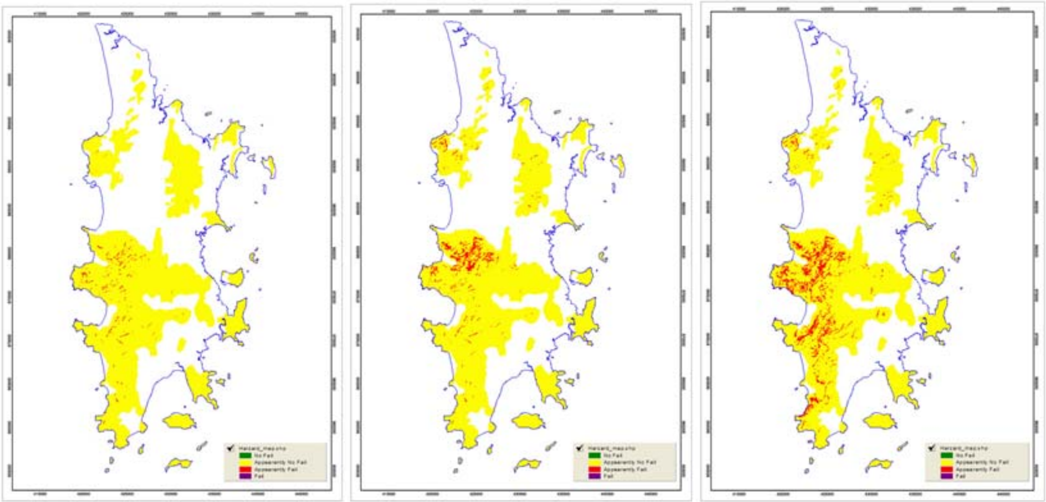
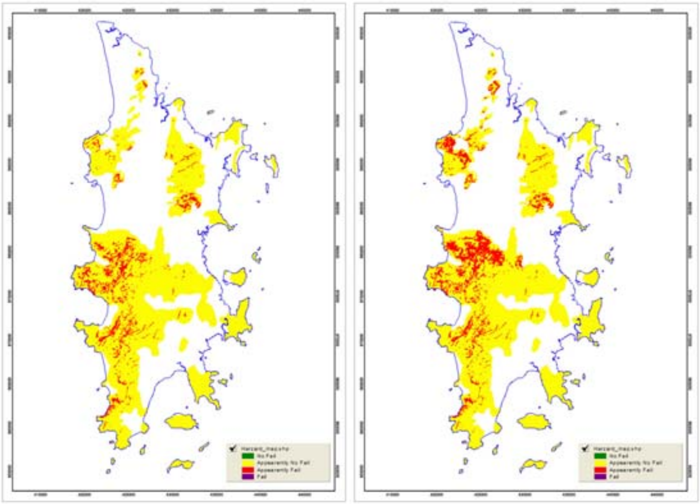


Figure 72 Area of failure cut slope classes considered by including 7 related factors and RMR factor



(a) 1 year (b) 5 years (c) 20 years



(d) 50 years (e) 100 years

Figure 73 The failure cut slope of hazard map in Phuket showning rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (RMR factor included)

Table 50 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and RMR factor

Return period of rainfall year	Landslide classify	pixel	Area (km^2)	%
1	Fail	6,264	3.92	0.71
	No fail	872,153	545.10	99.29
5	Fail	17,828	11.14	2.03
	No fail	860,589	537.87	97.97
20	Fail	38,968	24.36	4.44
	No fail	839,449	524.66	95.56
50	Fail	44,010	27.51	5.01
	No fail	834,407	521.50	94.99
100	Fail	62,019	38.76	7.06
	No fail	816,398	510.25	92.94

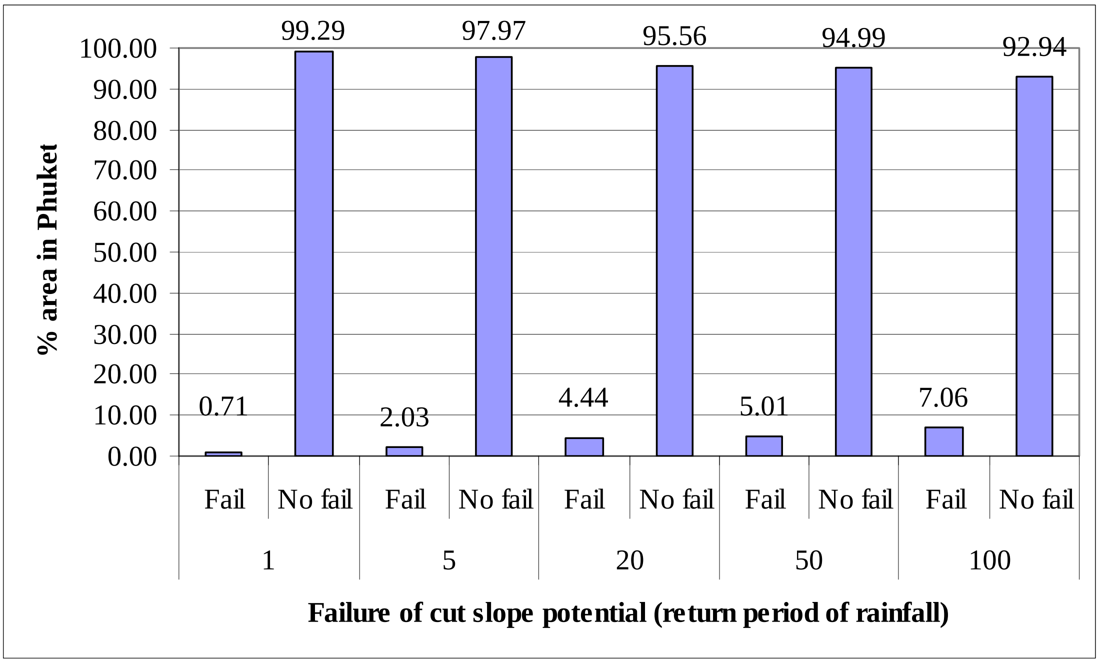


Figure 74 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and RMR factor

Failure Verification (SMR included)

Fig 75 shows relationship between failure of cut slope and SMR factor. Fig 76 shows relationship between non failure of cut slope and SMR factor. Fig 77 shows normal distribution of total score considered 7 related factors and SMR factor to classify by slope condition.

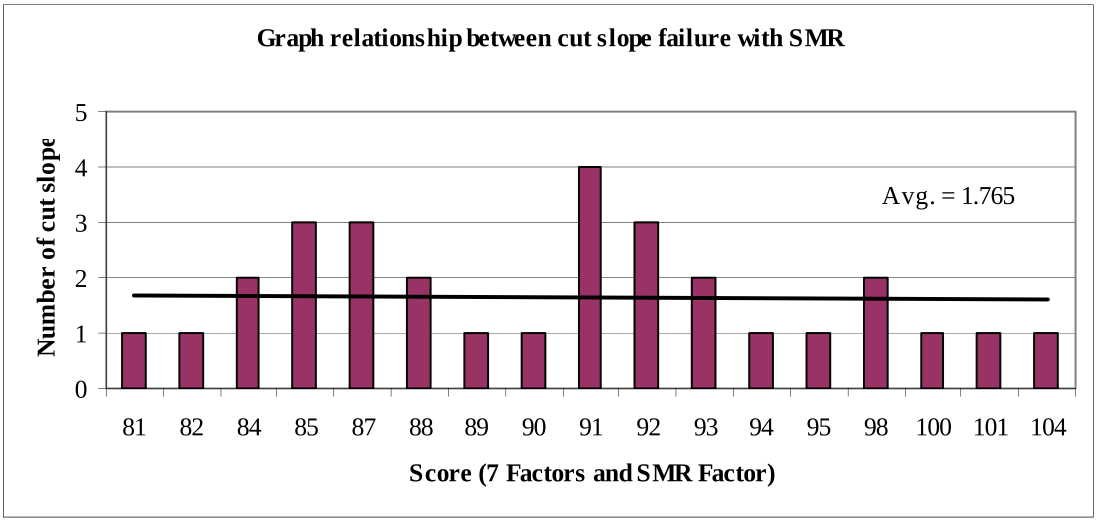


Figure 75 Graph relationships between cut slope failures and SMR factor

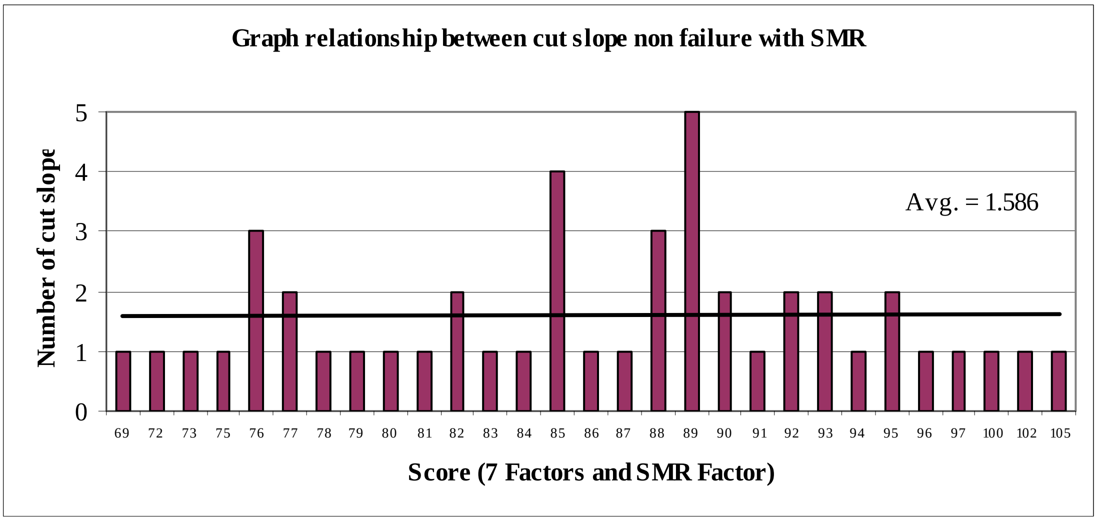


Figure 76 Graph relationships between cut slope non failures and SMR factor

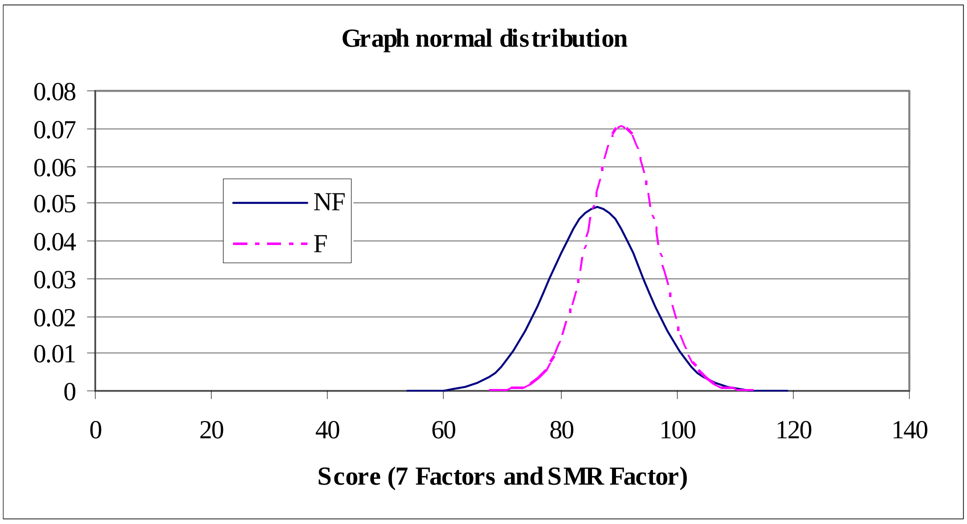


Figure 77 Normal distribution of total score (7 related factors and SMR factor) classified by slope condition

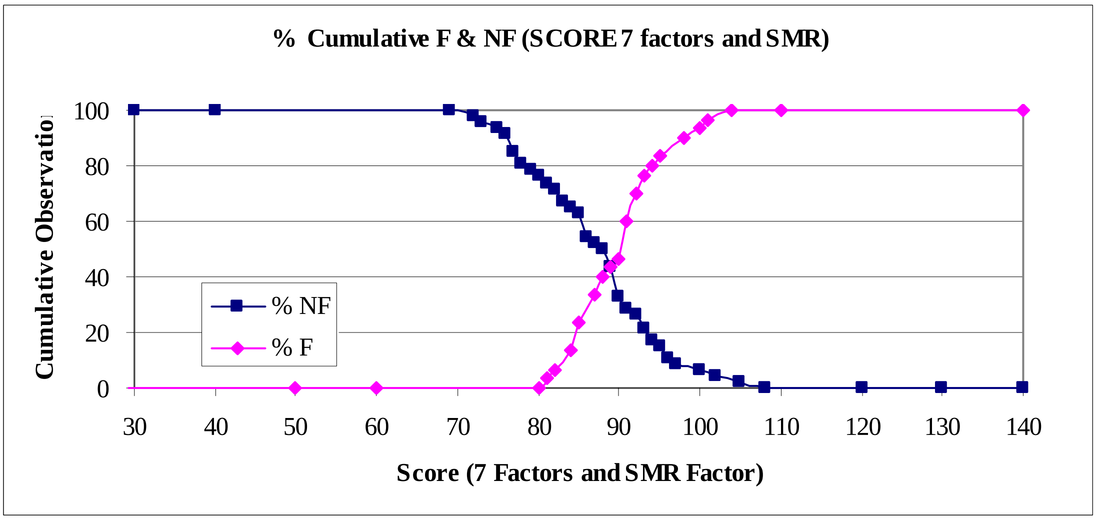


Figure 78 Cumulative frequency of total score (7 related factors and SMR factor) classified by slope condition

Fig 78 shows cumulative frequency of total score considered 7 related factors and SMR factor to classify by slope condition. Fig 79 shows cut slope failure potential classified by 7 related factors and SMR factor.

Table 51 shows the landslide potential and the range of total score considering RMR factor for all return periods of rainfall which considered from cumulative of failure and non-failure frequency (Fig 79).

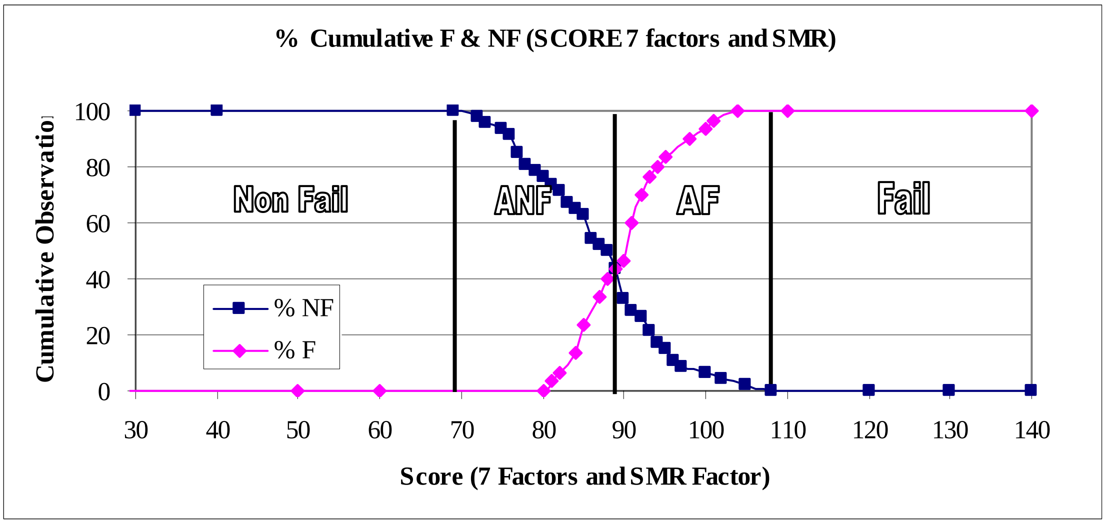


Figure 79 Cut slope failure potential classified by 7 related factors and SMR factor

Table 51 The landslide potential and the range of total score considering SMR factor for all rainfall return period.

Failure cut slope Classes	Range of Score
Very high potential	107-140
High potential	89-107
Low potential	69-89
Very low potential	30-69

Processing Cut Slope Failure Map and Hazard Map by Considering SMR Factor Included

In this section, the processing of landslide hazard map due to cut slope determined the numerical rating of 7 related factors and SMR factor following weighting factor method (Table 40). The weight-rating values of each parameter determined in each 25x25 square meter grid cell, in which the summation of weight-rating values were classified range of score by cut slope failure classes (Table 42). The result are shown in Fig 80. Table 52 and Fig 82 show area of cut slope failure classes considered by 7 related factors and SMR factor included.

Fig 84 (a) to (e) shows the results of processing of landslide hazard map due to cut slope considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by cumulative of failure and non-failure frequency which was 89 score. Fig 84 shows landslide hazard map due to cut slope using 1, 5, 20, 50 and 100 years return periods of rainfall considered 7 related factors and SMR factor included. Predicted landslide hazard area due to cut slope for 5 return periods of rainfall considered 7 related factors and SMR factor is shown in Table 53 and Fig 85. The plan area of landslide hazard due to cut slope was 2.09%, 4.05%, 8.75%, 10.64% and 12.71% for 1, 5, 20, 50 and 100 years return period of rainfall.

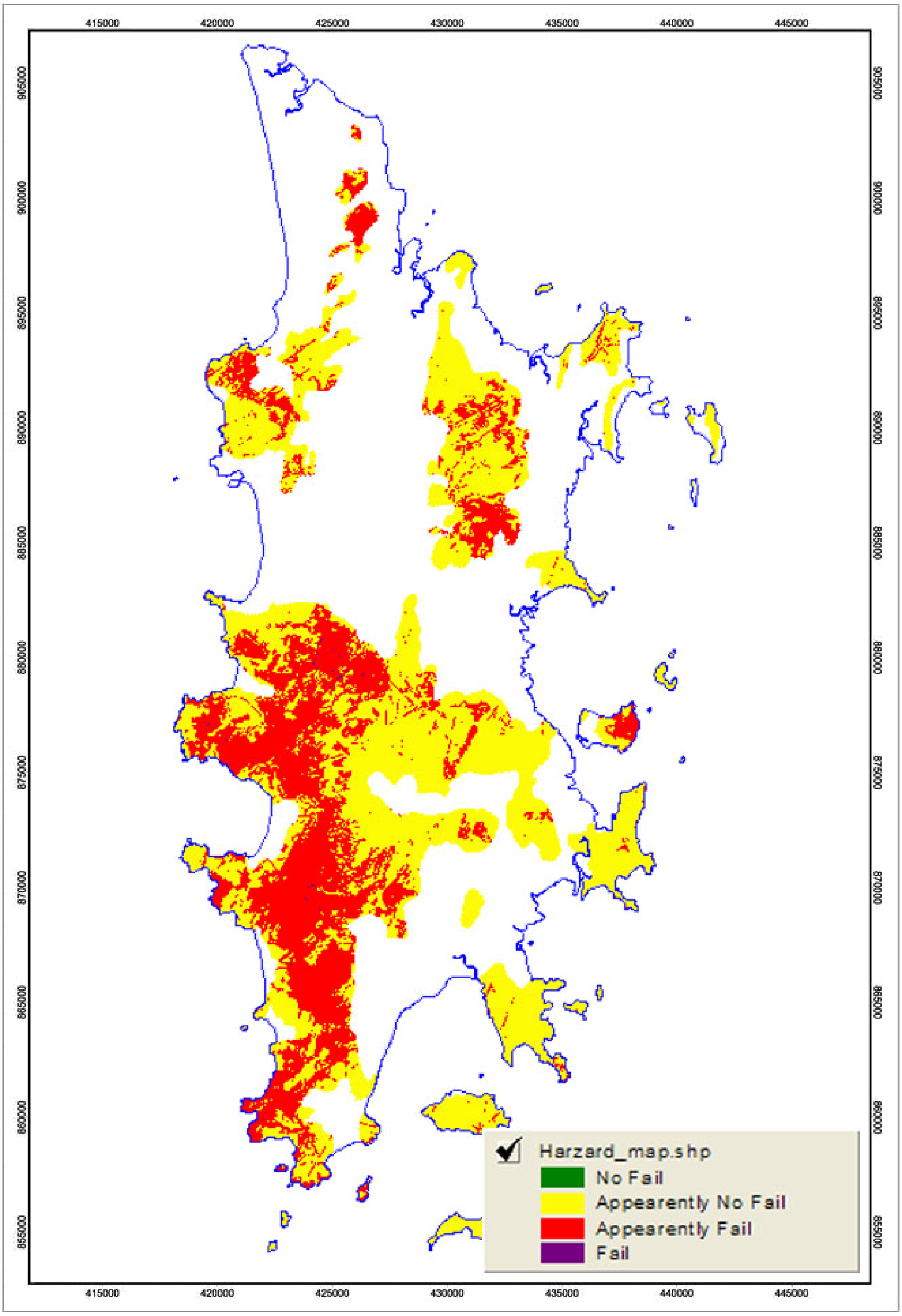
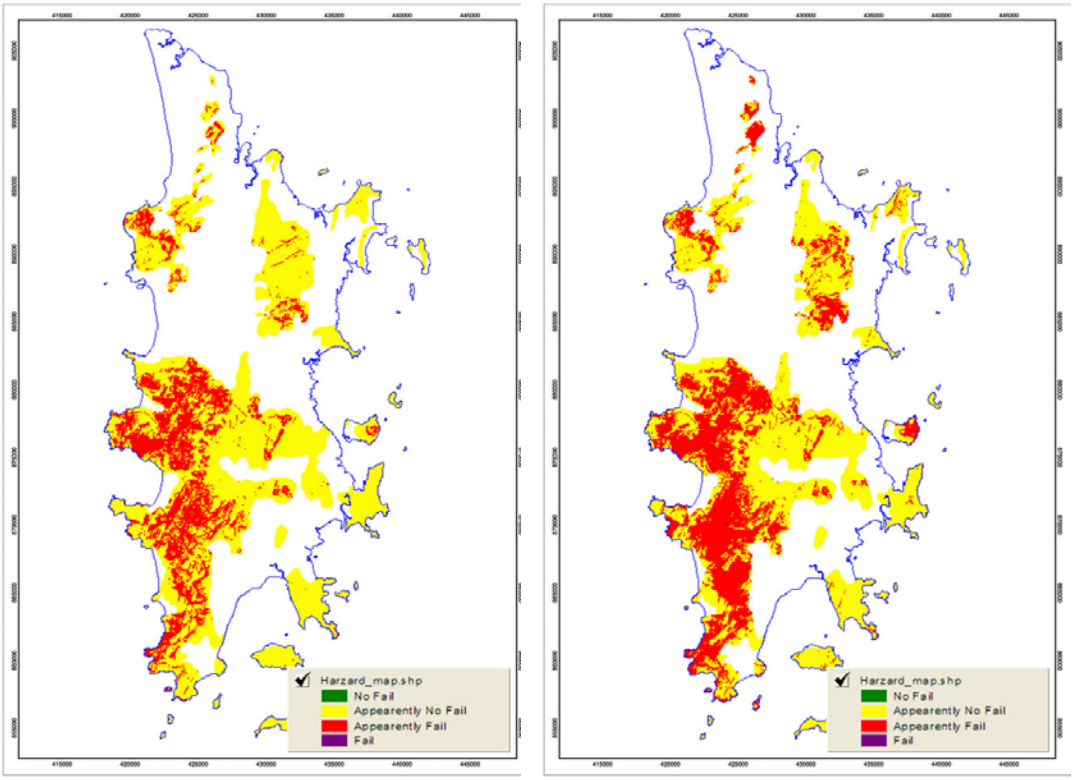


Figure 80 Area of failure cut slope classes considered by including 7 related factors and SMR factor

Table 52 Area of failure cut slope classes considered by including 7 related factors and SMR factor

Score	Failure cut slope Classes	pixel	Area (km^2)	%
96 - 118	Fail	604	0.38	0.07
74 - 96	Apparently fail	169,851	106.16	19.34
69 - 74	Apparently no fail	270,209	168.88	30.76
30 - 69	No fail	437,753	273.60	49.83
	Sum	878,417	549.01	100.00

Figure 81 Area of failure cut slope classes considered by including 7 related factors and SMR factor



(a) 7 factors and RMR factor (b) 7 factors and SMR factor

Figure 82 Comparing between the failure cut slope hazard map

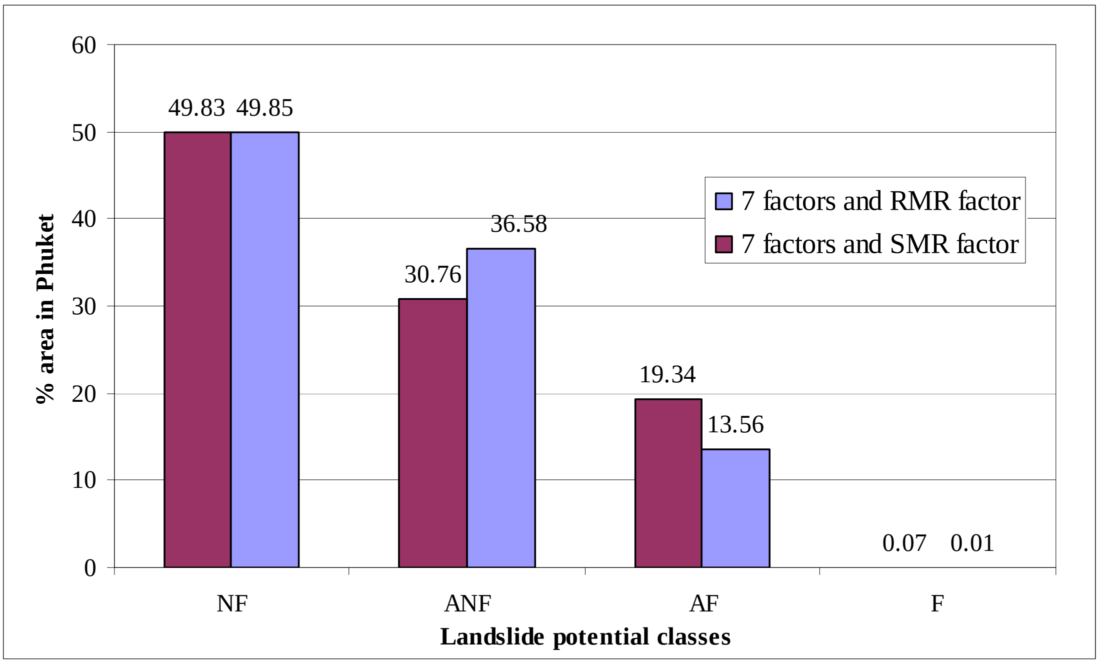
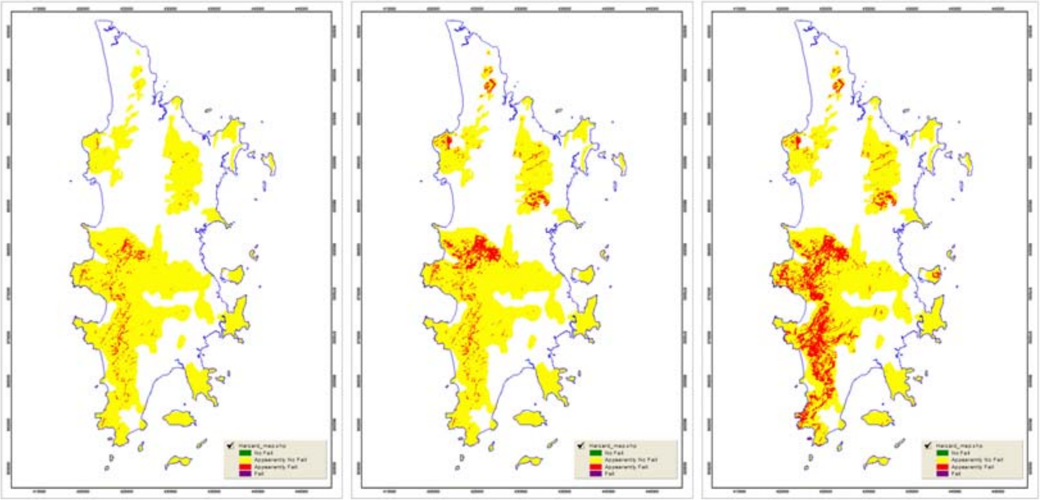
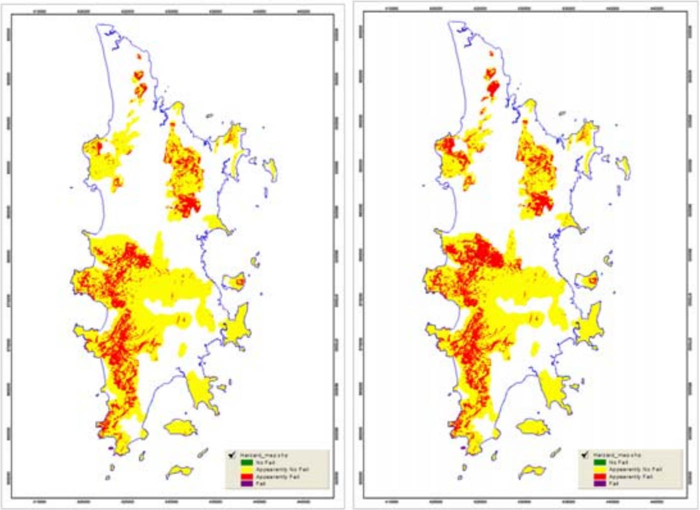


Figure 83 Comparison of failure cut slope hazard classes



(a) 1 year (b) 5 years (c) 20 years



(d) 50 years (e) 100 years

Figure 84 The failure cut slope of hazard map in Phuket showing rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (SMR factor included)

Table 53 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and SMR factor

Return period of rainfall year	Landslide classify	pixel	Area (km^2)	%
1	Fail	18,360	11.48	2.09
	No fail	860,057	537.54	97.91
5	Fail	35,577	22.24	4.05
	No fail	842,840	526.78	95.95
20	Fail	76,879	48.05	8.75
	No fail	801,538	500.96	91.25
50	Fail	93,461	58.41	10.64
	No fail	784,956	490.60	89.36
100	Fail	111,674	69.80	12.71
	No fail	766,743	479.21	87.29

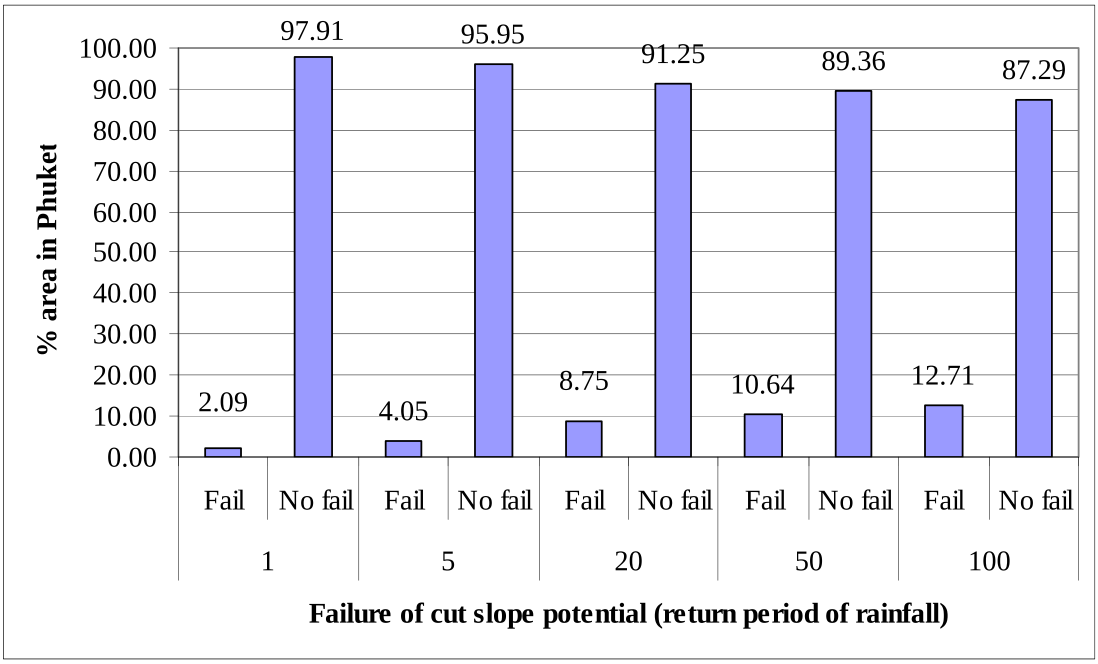


Figure 85 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and SMR factor

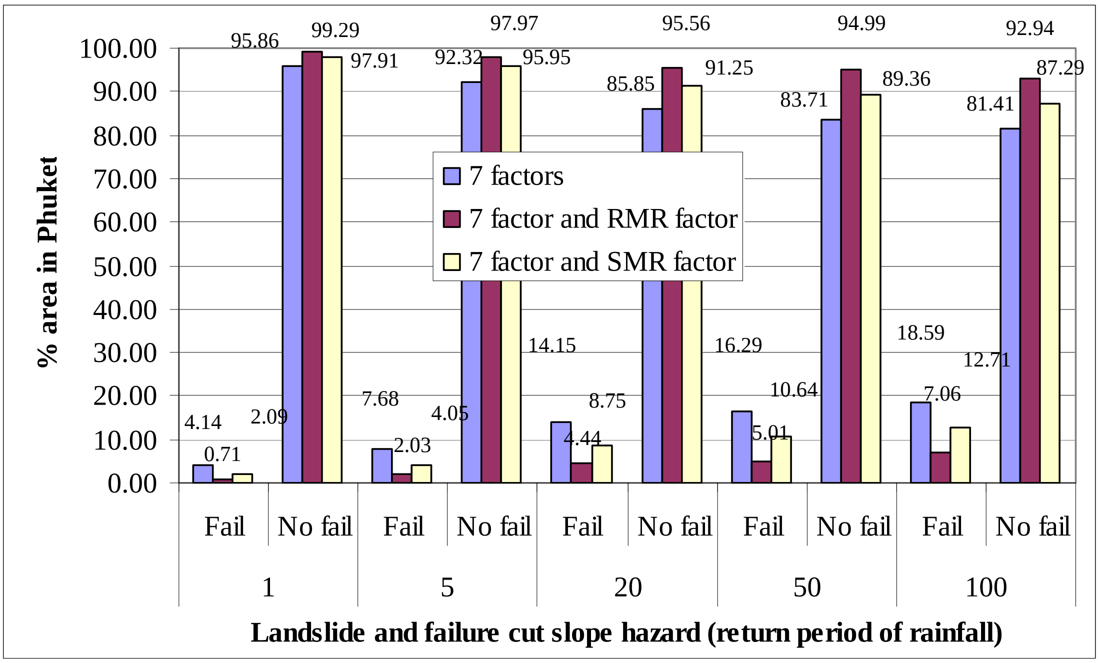


Figure 86 Comparison of landslide hazard

Fig 86 shows comparison between the landslide hazard map which considered only 7 related factors, 7 related factors and RMR factor included and 7 related factors and SMR factor included. The results were slightly different.

Logistic Multiple Regression Analysis (RMR factors included)

The linear logistic modal was represented by the equation:

For cumulative rainfall intensity 3 days

Y = -4.86459 + (6.14587*[W_eng])-(0.14011*[Rmr])
+ (0.001097*[Slope_val]) + (0.061088*[W_landuse])
- (0.26825*[W_drain]) - (0.00103*[Ele_value])
+ (0.101402*[W_linea]) + (0.068205*[Intensity])
- (0.04469*[W_soil]) - (4.45102*[W_rocktype])

For cumulative rainfall intensity 3 days (100 year return period)

Y = 7.706127 + (6.1245*[W_eng]) - (0.14707*[Rmr]) -
(0.0097*[Slope_val])
- (0.00849*[W_landuse]) - (0.3332*[W_drain]) - (0.0015*[Ele_value])
+ (0.07567*[W_linea]) - (0.00602*[Intensity]) - (0.21034*[W_soil])
- (4.30685*[W_rocktype])

and

P = 1/(1+exp(-Y))

Is the estimated probability of failure of cut slope at a given cell.

When W_rocktype = weight factor index of rock type (discrete value)
W_linea = weight factor index of lineament zone (discrete value)
Slope_val = slope in degree (continues value)
Ele_value = elevation in meter (continues value)
W_landuse = weight factor index of land use (discrete value)
W_drain = weight factor index of drainage zone (discrete value)
W_soil = weight factor index of soil characteristic (discrete value)
W_eng = weight factor index of engineering properties (discrete value)
Intensity = rainfall intensity in mm. (continues value)
Rmr = rock mass rating value (continues value)
Y = slope condition
P = probability

Table 54 Variable means between failure and non-failure of cut slope

Factors	Fail			No Fail		
	Mean	Std. Deviation	N	Mean	Std. Deviation	N
DRAINAGE	1.536	1.170	28	2.114	1.471	35
ELEVATION	116.008	102.658	28	98.442	48.686	35
ENGINEERING	3.964	0.189	28	3.686	0.758	35
INTENSITY (1 year)	138.214	4.756	28	133.286	6.636	35
INTENSITY (100 year)	406.250	33.765	28	421.071	50.345	35
LAND USE	3.000	1.247	28	3.229	1.262	35
LINEAMENT	1.857	1.671	28	2.486	1.961	35
ROCKTYPE	4.964	0.189	28	4.657	0.906	35
SLOPE	20.750	6.709	28	21.749	6.546	35
SOILTEXTURE	2.857	0.356	28	2.571	0.698	35
RMR	35.250	9.724	28	55.171	9.913	35

Table 55 Result of linear regression analysis for cumulative rainfall intensity 3 days (RMR factors included)

SUMMARY OUTPUT RMR (Cumulative rainfall intensity 3 days)

Regression Statistics	
Multiple R	0.7722
R Square	0.5962
Adjusted R Square	0.5186
Standard Error	2.0505
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	322.8620	32.28620	7.6792	2.20303E-07
Residual	52	218.6269	4.20436		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-4.86459	8.04871	-0.60439	0.54821	-21.01550	11.28632
ENGINEERING	6.14587	4.91512	1.25040	0.21675	-3.71703	16.00877
RMR	-0.14011	0.02113	-6.63047	0.00000	-0.18252	-0.09771
SLOPE	0.00110	0.04339	0.02529	0.97992	-0.08596	0.08816
LANDUSE	0.06109	0.22690	0.26923	0.78882	-0.39422	0.51640
DRAINAGE	-0.26825	0.22376	-1.19882	0.23603	-0.71726	0.18076
ELEVATION	-0.00103	0.00389	-0.26380	0.79298	-0.00884	0.00679
LINEAMENT	0.10140	0.16195	0.62611	0.53398	-0.22358	0.42639
INTENSITY	0.06820	0.05159	1.32212	0.19191	-0.03531	0.17172
SOILTEXTURE	-0.04469	0.72928	-0.06128	0.95137	-1.50810	1.41872
ROCKTYPE	-4.45102	4.09832	-1.08606	0.28246	-12.67491	3.77286

Table 56 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	1.742
ELEVATION	0.049
ENGINEERING	0.000
INTENSITY (1 year)	1.947
LANDUSE	0.023
LINEAMENT	1.987
RMR	12.478
ROCKTYPE	0.000
SOILTEXTURE	0.234
SLOPE	0.033

Table 57 Result of linear regression analysis for cumulative rainfall intensity 3 days, 100 years return period (RMR factors included)

SUMMARY OUTPUT   RMR (100 Years return period of rainfall)

Regression Statistics	
Multiple R	0.7673
R Square	0.5888
Adjusted R Square	0.5097
Standard Error	2.0694
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	318.8034	31.88034	7.4445	3.38983E-07
Residual	52	222.6855	4.28241		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	7.70613	4.03613	1.90928	0.06175	-0.39297	15.80522
ENGINEERING	6.12450	5.12974	1.19392	0.23793	-4.16907	16.41807
RMR	-0.14707	0.02019	-7.28557	0.00000	-0.18758	-0.10656
SLOPE	-0.00970	0.04323	-0.22439	0.82333	-0.09645	0.07705
LANDUSE	-0.00849	0.22495	-0.03773	0.97005	-0.45988	0.44290
DRAINAGE	-0.33322	0.21886	-1.52255	0.13393	-0.77240	0.10595
ELEVATION	-0.00150	0.00393	-0.38155	0.70435	-0.00938	0.00638
LINEAMENT	0.07567	0.16162	0.46820	0.64160	-0.24864	0.39998
INTENSITY	-0.00602	0.00687	-0.87658	0.38475	-0.01981	0.00776
SOILTEXTURE	-0.21034	0.74511	-0.28229	0.77884	-1.70550	1.28483
ROCKTYPE	-4.30685	4.24387	-1.01484	0.31488	-12.82280	4.20910

Table 58 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	3.146
ELEVATION	0.580
ENGINEERING	0.000
INTENSITY (1 year)	0.199
LANDUSE	0.579
LINEAMENT	1.049
RMR	13.298
ROCKTYPE	0.000
SOILTEXTURE	0.001
SLOPE	0.205

Table 54 shows variable means between failure and non-failure of cut slope. Table 55 shows result of linear regression analysis for cumulative rainfall intensity 3 days (RMR factors included). Table 57 shows result of linear regression analysis for cumulative rainfall intensity 3 days, 100 year return period (RMR factors included). Table 56 and Table 58 show results of enter logistic procedure in which RMR factor was 68.63 time higher than other variables. Therefore, RMR factor may overwhelm the effects of the other variables in predicting landslide of cut slope.

Processing Cut Slope Probability of Failure Map by Considering RMR Factor Included

Fig 87 shows probability of failure of sensitive area for cut slope for 1 year rainfall return period. Fig 88 shows probability of failure of sensitive area for cut slope for 100 year rainfall return period by considering RMR factor. Table 59 shows parameter means and distribution of predictive failure of cut slope (RMR included).

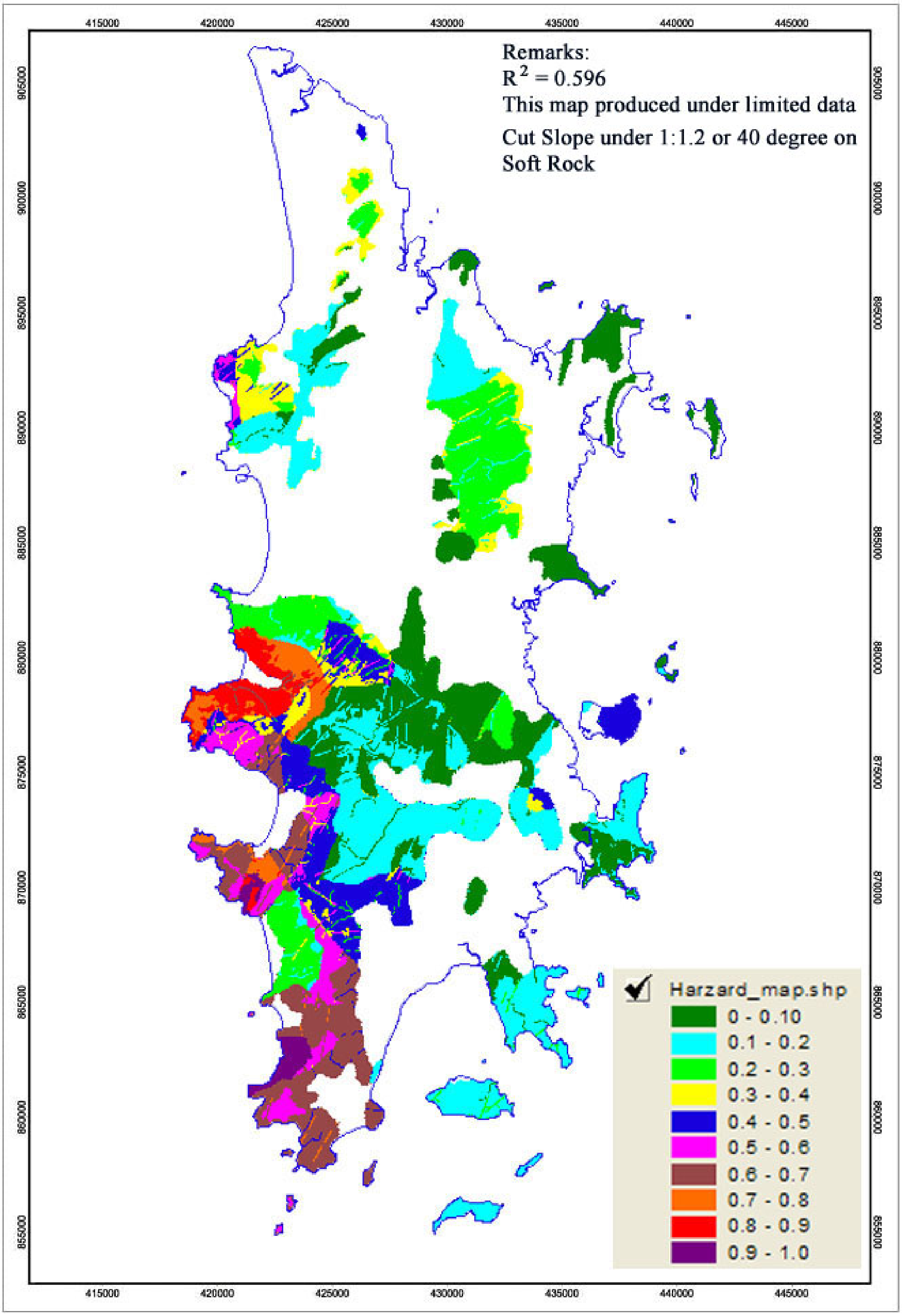


Figure 87 Probability of failure of sensitive area for cut slope for 1 year rainfall return period (RMR factor included)

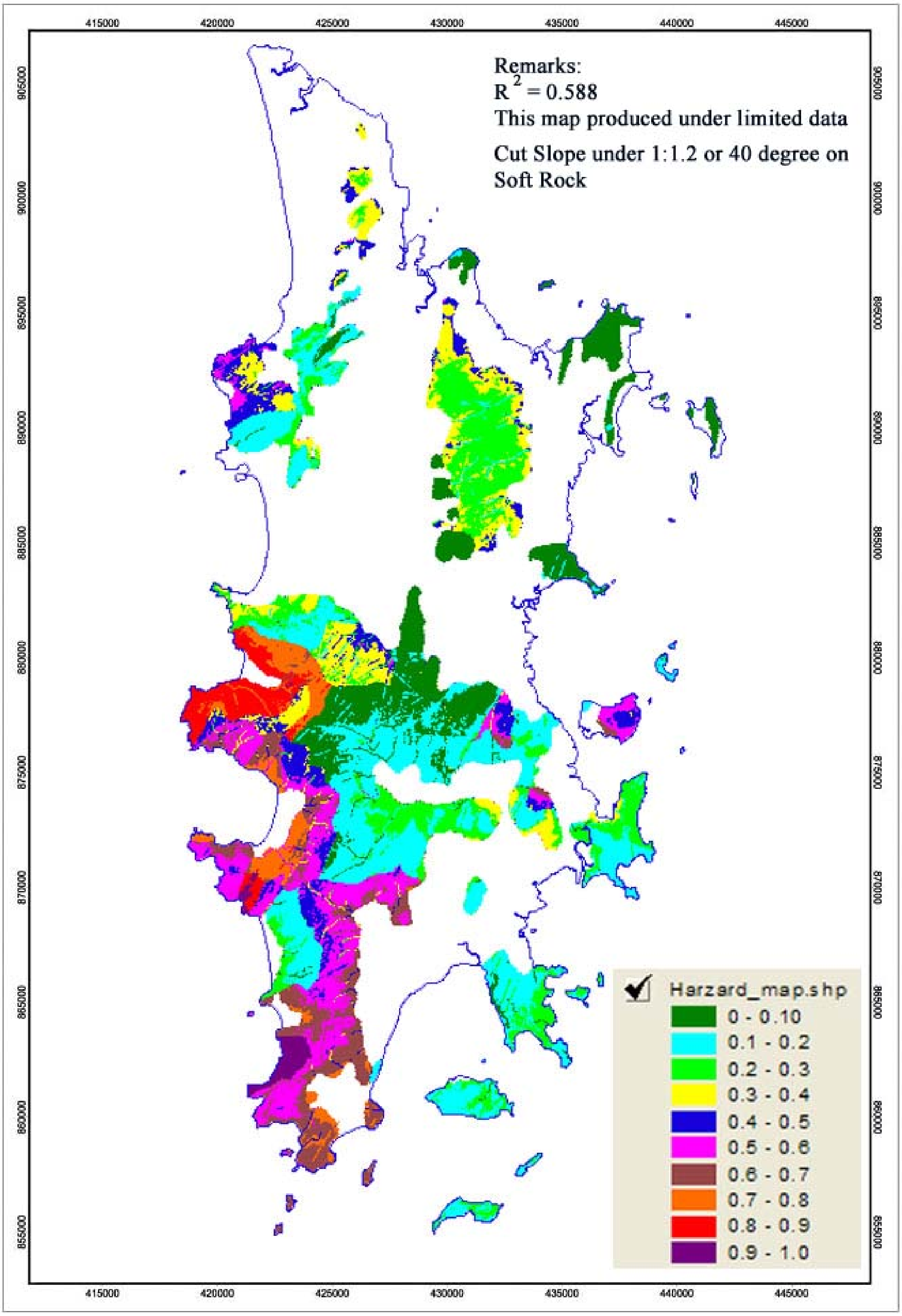


Figure 88 Probability of failure of sensitive area for cut slope for 100 years rainfall return period (RMR factor included)

Table 59 Parameter means and distribution of predictive failure of cut slope (RMR included)

RMR cumulative rainfall intensity 3 days

	Parameter																						
Probability	1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	11.9	10.6	101.0	100.0	4.3	0.5	1.0	0.4	1.1	0.5	2.1	0.6	3.2	1.2	3.3	0.5	128.1	5.2	53.7	5.3	-2.7095	0.062	90,970
0.1-0.2	11.1	10.6	87.5	82.8	4.8	0.4	1.2	0.8	1.0	0.4	2.3	0.7	3.2	1.2	3.8	0.4	129.3	7.4	54.1	5.1	-1.8624	0.134	124,573
0.2-0.3	15.6	10.5	155.7	103.5	5.0	0.2	1.1	0.5	1.1	0.5	2.8	0.5	2.4	1.4	4.0	0.2	131.2	8.2	51.1	4.6	-1.1043	0.249	62,063
0.3-0.4	14.5	10.3	129.4	108.5	5.0	0.0	1.1	0.7	1.1	0.6	2.6	0.5	3.4	1.2	4.0	0.0	128.4	4.9	47.8	1.2	-0.6836	0.335	24,406
0.4-0.5	16.0	10.6	162.2	117.8	5.0	0.0	1.1	0.6	1.1	0.6	2.8	0.5	3.6	0.9	4.0	0.0	135.1	1.8	47.4	1.1	-0.2068	0.448	40,430
0.5-0.6	15.3	9.7	158.9	93.3	5.0	0.0	1.3	1.0	1.0	0.1	2.9	0.3	3.1	1.3	4.0	0.0	140.2	5.0	47.0	1.3	0.2265	0.556	21,976
0.6-0.7	11.9	10.3	71.0	62.7	5.0	0.0	1.1	0.6	1.0	0.4	2.6	0.5	3.5	1.0	4.0	0.0	143.2	3.8	46.6	2.4	0.5713	0.639	42,021
0.7-0.8	16.1	10.8	218.5	141.2	5.0	0.0	1.3	1.0	1.0	0.2	2.9	0.3	2.5	1.5	4.0	0.0	137.7	4.5	37.9	3.8	1.2202	0.772	12,878
0.8-0.9	15.2	10.9	84.2	74.8	5.0	0.0	1.2	0.8	1.0	0.0	2.8	0.4	3.0	1.3	4.0	0.0	135.6	2.3	35.5	0.5	1.5753	0.829	14,072
0.9-1.0	15.9	9.0	90.3	61.4	5.0	0.0	1.0	0.4	1.0	0.0	3.0	0.2	3.3	1.1	4.0	0.0	145.0	0.0	32.7	1.2	2.6046	0.931	5,842

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

RMR cumulative rainfall intensity 3 days , 100 year return period

	Parameter																						
Probability	1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	15.4	11.0	136.5	120.8	4.4	0.5	1.0	0.4	1.2	0.8	2.4	0.5	3.3	1.2	3.4	0.5	467.0	48.6	54.6	5.5	-2.5232	0.074	54,139
0.1-0.2	11.5	10.8	95.5	84.4	4.5	0.5	1.1	0.8	1.1	0.5	2.2	0.7	3.1	1.2	3.5	0.5	430.2	48.3	54.4	4.3	-1.7559	0.147	112,521
0.2-0.3	10.6	10.8	105.0	113.2	4.7	0.4	1.2	0.8	1.1	0.4	2.3	0.7	2.7	1.3	3.7	0.4	434.3	84.4	52.2	5.0	-1.1622	0.238	79,043
0.3-0.4	14.3	10.8	127.9	98.9	5.0	0.1	1.1	0.5	1.1	0.6	2.7	0.5	3.0	1.3	4.0	0.1	480.2	53.6	49.2	3.5	-0.6974	0.332	39,958
0.4-0.5	14.0	10.7	148.1	126.4	5.0	0.0	1.1	0.7	1.1	0.6	2.6	0.5	3.6	0.9	4.0	0.0	440.6	57.4	47.5	1.0	-0.2119	0.447	30,489
0.5-0.6	15.9	9.4	135.6	82.4	5.0	0.0	1.1	0.6	1.0	0.3	2.8	0.5	3.3	1.2	4.0	0.0	375.0	35.7	47.3	1.2	0.2102	0.552	45,915
0.6-0.7	9.2	8.7	62.4	62.7	5.0	0.0	1.1	0.8	1.0	0.2	2.5	0.6	3.4	1.0	4.0	0.0	359.3	29.3	46.8	2.1	0.6301	0.653	32,169
0.7-0.8	11.8	11.8	146.3	146.6	5.0	0.0	1.1	0.8	1.1	0.5	2.7	0.5	3.2	1.2	4.0	0.0	404.1	46.2	40.5	4.8	1.0777	0.746	19,095
0.8-0.9	14.2	10.1	87.4	73.6	5.0	0.0	1.1	0.7	1.0	0.0	2.8	0.4	2.7	1.4	4.0	0.0	430.9	24.8	35.5	0.6	1.7287	0.849	15,668
0.9-1.0	14.6	8.9	85.7	60.4	5.0	0.0	1.1	0.6	1.0	0.0	3.0	0.2	3.3	1.1	4.0	0.0	342.8	32.5	1.0	5.5	7.2847	0.999	5,233

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

Logistic Multiple Regression Analysis by SMR Factor Included

The linear logistic modal was represented by the equation:

For cumulative rainfall intensity 3 days

$$\begin{aligned}Y = {} & -2.57172 + (8.51002*[\text{W\_eng}]) - (0.1337*[\text{Smr}]) - (0.0132*[\text{Slope\_val}]) \\ & - (0.05934*[\text{W\_landuse}]) - (0.1908*[\text{W\_drain}]) - (0.00177*[\text{Ele\_value}]) \\ & + (0.042322*[\text{W\_linea}]) + (0.056058*[\text{Intensity}]) - (0.04864*[\text{W\_soil}]) \\ & - (6.42077*[\text{W\_rocktype}])\end{aligned}$$

For cumulative rainfall intensity 3 days (100 year return period)

$$\begin{aligned}Y = {} & 6.892795 + (8.07922*[\text{W\_eng}]) - (0.14059*[\text{Smr}]) \\ & - (0.0221*[\text{Slope\_val}]) - (0.11774*[\text{W\_landuse}]) - (0.24265*[\text{W\_drain}]) \\ & - (0.00252*[\text{Ele\_value}]) + (0.00734*[\text{W\_linea}]) - (0.00282*[\text{Intensity}]) \\ & - (0.14739*[\text{W\_soil}]) - (5.97485*[\text{W\_rocktype}])\end{aligned}$$

and

$$P = 1/(1+\exp(-Y))$$

Is the estimated probability of failure of cut slope at a given cell.

When W_rocktype = weight factor index of rock type (discrete value)
W_linea = weight factor index of lineament zone (discrete value)
Slope_val = slope in degree (continues value)
Ele_value = elevation in meter (continues value)
W_landuse = weight factor index of land use (discrete value)
W_drain = weight factor index of drainage zone (discrete value)
W_soil = weight factor index of soil characteristic (discrete value)
W_eng = weight factor index of engineering properties (discrete value)
Intensity = rainfall intensity in mm. (continues value)
Rmr = rock mass rating value (continues value)
Y = slope condition
P = probability

Table 60 Variable means between failure and non-failure of cut slope

Factors	Fail			No Fail		
	Mean	Std. Deviation	N	Mean	Std. Deviation	N
DRAINAGE	1.536	1.170	28	2.114	1.471	35
ELEVATION	116.008	102.658	28	98.442	48.686	35
ENGINEERING	3.964	0.189	28	3.686	0.758	35
INTENSITY (1 year)	138.214	4.756	28	133.286	6.636	35
INTENSITY (100 year)	406.250	33.765	28	421.071	50.345	35
LANDUSE	3.000	1.247	28	3.229	1.262	35
LINEAMENT	1.857	1.671	28	2.486	1.961	35
ROCKTYPE	4.964	0.189	28	4.657	0.906	35
SLOPE	20.750	6.709	28	21.749	6.546	35
SOILTEXTURE	2.857	0.356	28	2.571	0.698	35
SMR	33.227	9.723	28	53.451	10.879	35

Table 61 Result of linear regression analysis for cumulative rainfall intensity 3 days (SMR factors included)

SUMMARY OUTPUT SMR (Cumulative rainfall intensity 3 days)

Regression Statistics	
Multiple R	0.7642
R Square	0.5840
Adjusted R Square	0.5040
Standard Error	2.0814
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	316.2238	31.62238	7.2997	4.43655E-07
Residual	52	225.2651	4.33202		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.57172	8.36155	-0.30757	0.75964	-19.35038	14.20694
ENGINEERING	8.51002	4.97672	1.70996	0.09323	-1.47650	18.49654
SMR	-0.13370	0.02085	-6.41367	0.00000	-0.17553	-0.09187
SLOPE	-0.01320	0.04396	-0.30016	0.76525	-0.10141	0.07502
LANDUSE	-0.05934	0.23041	-0.25754	0.79778	-0.52168	0.40301
DRAINAGE	-0.19080	0.22673	-0.84155	0.40390	-0.64577	0.26416
ELEVATION	-0.00177	0.00399	-0.44303	0.65958	-0.00977	0.00623
LINEAMENT	0.04232	0.16487	0.25670	0.79842	-0.28851	0.37315
INTENSITY	0.05606	0.05324	1.05301	0.29721	-0.05077	0.16288
SOILTEXTURE	-0.04864	0.74049	-0.06569	0.94788	-1.53454	1.43726
ROCKTYPE	-6.42077	4.14554	-1.54884	0.12749	-14.73941	1.89787

Table 62 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	0.855
ELEVATION	0.355
ENGINEERING	0.000
INTENSITY (1 year)	0.661
LANDUSE	0.408
LINEAMENT	0.646
ROCKTYPE	0.000
SOILTEXTURE	0.144
SLOPE	0.188
SMR	11.700

Table 63 Result of linear regression analysis for cumulative rainfall intensity 3 days, 100 years return period (SMR factors included)

SUMMARY OUTPUT SMR (100 Years return period of rainfall)

Regression Statistics	
Multiple R	0.7592
R Square	0.5764
Adjusted R Square	0.4950
Standard Error	2.1002
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	312.1199	31.21199	7.0760	6.75662E-07
Residual	52	229.3690	4.41094		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	6.89279	4.09276	1.68414	0.09815	-1.31992	15.10551
ENGINEERING	8.07922	5.20070	1.55349	0.12637	-2.35675	18.51519
INTENSITY	-0.00282	0.00708	-0.39824	0.69209	-0.01702	0.01138
LANDUSE	-0.11774	0.22689	-0.51892	0.60602	-0.57302	0.33755
DRAINAGE	-0.24265	0.22283	-1.08895	0.28120	-0.68979	0.20449
SMR	-0.14059	0.01988	-7.07232	0.00000	-0.18048	-0.10070
SLOPE	-0.02210	0.04368	-0.50588	0.61508	-0.10975	0.06555
ELEVATION	-0.00252	0.00402	-0.62659	0.53367	-0.01059	0.00555
LINEAMENT	0.00734	0.16392	0.04477	0.96446	-0.32160	0.33628
SOILTEXTURE	-0.14739	0.75579	-0.19501	0.84615	-1.66400	1.36922
ROCKTYPE	-5.97485	4.30110	-1.38915	0.17071	-14.60562	2.65593

Table 64 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	1.844
ELEVATION	1.051
ENGINEERING	0.000
INTENSITY (100 year)	0.161
LANDUSE	0.771
LINEAMENT	0.190
ROCKTYPE	0.000
SOILTEXTURE	0.299
SLOPE	0.295
SMR	11.838

Table 60 shows variable means between failure and non-failure of cut slope. Table 61 shows result of linear regression analysis for cumulative rainfall intensity 3 days (SMR factors included). Table 63 shows result of linear regression analysis for cumulative rainfall intensity 3 days, 100 year return period (SMR factors included). Table 62 and Table 64 show results of enter logistic procedure in which SMR factor was 75.10 time higher than other variables. Therefore, SMR factor may overwhelm the effects of the other variables in predicting landslide of cut slope.

Processing Cut Slope Probability of Failure Map by Considering SMR Factor Included

Fig 89 shows probability of failure of sensitive area for cut slope for 1 year rainfall return period. Fig 90 shows probability of failure of sensitive area for cut slope for 100 year rainfall return period by considering SMR factor. Table 65 shows parameter means and distribution of predictive failure of cut slope (SMR included).

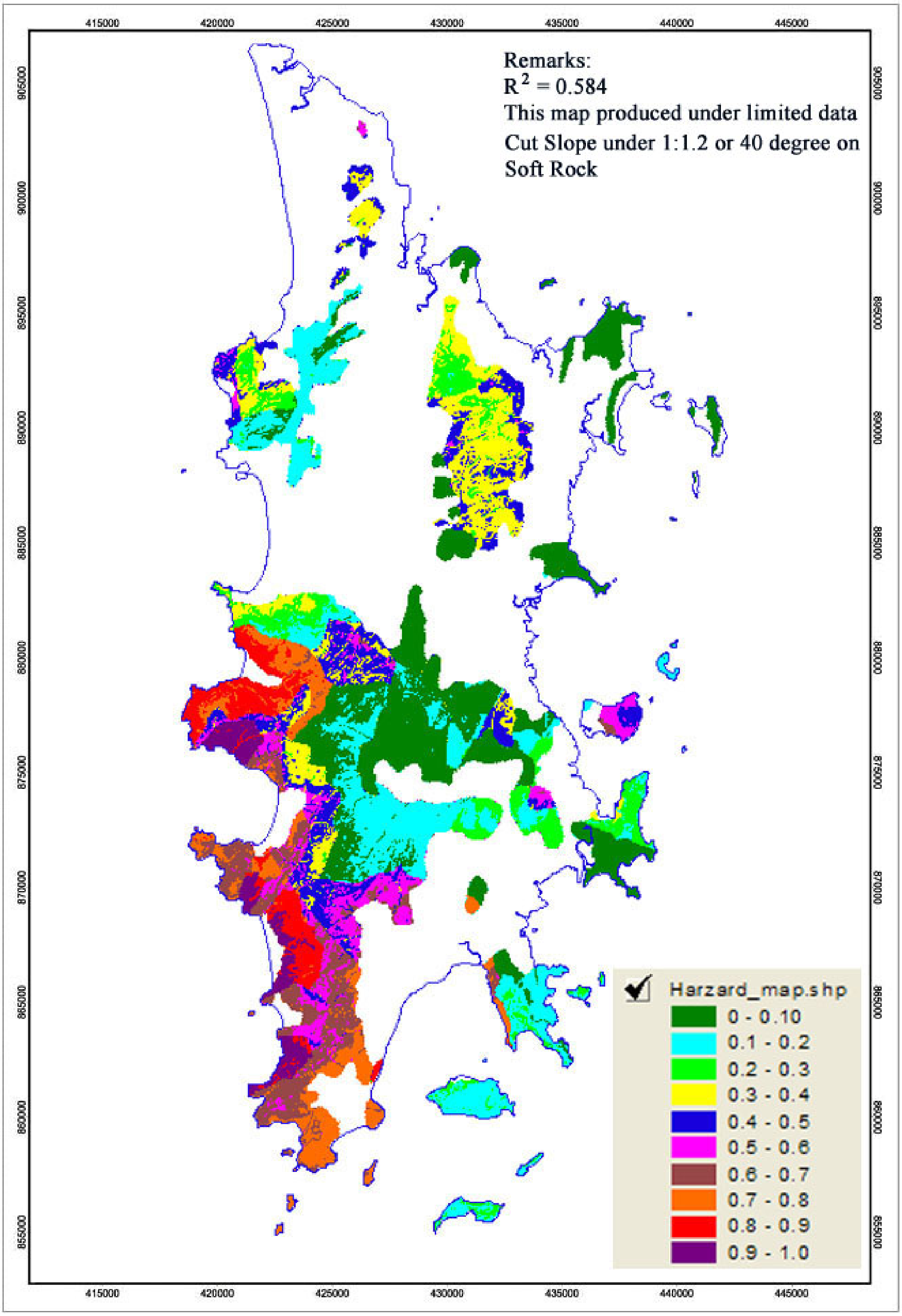


Figure 89 Probability of failure of sensitive area for cut slope for 1 year rainfall return period (SMR factor included)

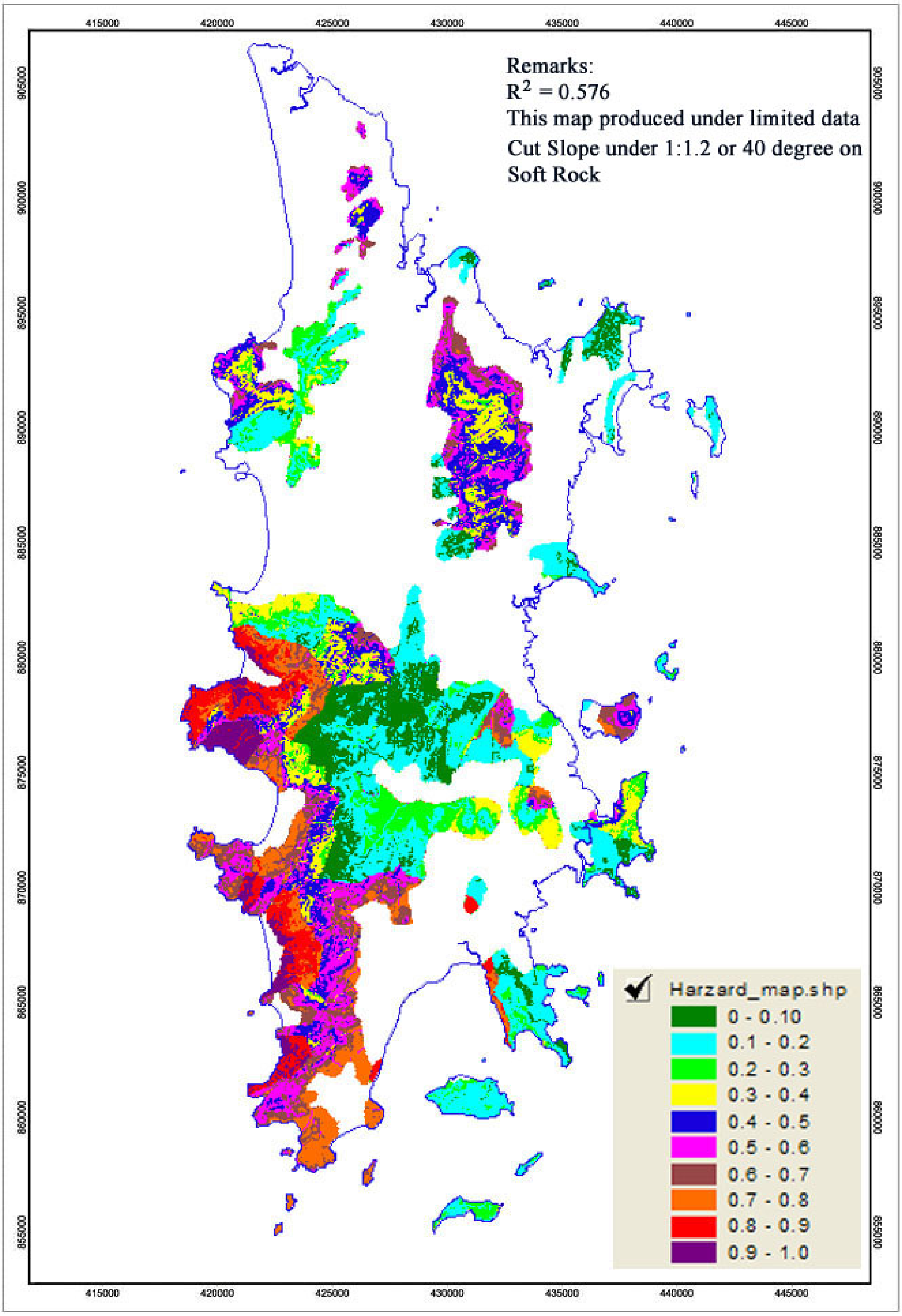


Figure 90 Probability of failure of sensitive area for cut slope for 100 years rainfall return period (SMR factor included)

Table 65 Parameter means and distribution of predictive failure of cut slope (SMR included)

SMR cumulative rainfall intensity 3 days

	Parameter																						
Probability	1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	13.0	10.9	102.7	100.5	4.3	0.4	1.1	0.6	1.1	0.5	2.1	0.6	3.4	1.1	3.3	0.4	128.6	5.3	51.1	5.9	-2.5854	0.070	95,313
0.1-0.2	11.0	10.5	92.8	79.8	4.8	0.4	1.1	0.7	1.0	0.4	2.3	0.7	3.2	1.2	3.8	0.4	132.7	5.8	55.8	5.5	-1.8023	0.142	77,573
0.2-0.3	9.3	10.9	76.0	101.1	4.5	0.5	1.1	0.5	1.1	0.5	2.6	0.5	2.5	1.4	3.5	0.5	135.1	9.5	47.7	5.3	-1.1274	0.245	48,001
0.3-0.4	16.7	10.6	179.4	122.1	5.0	0.2	1.1	0.5	1.1	0.6	2.8	0.5	2.6	1.4	4.0	0.2	127.4	7.0	45.3	2.4	-0.6156	0.351	48,120
0.4-0.5	14.5	10.3	142.1	93.8	5.0	0.0	1.1	0.7	1.1	0.5	2.7	0.6	3.1	1.3	4.0	0.0	130.9	5.2	44.8	0.9	-0.2133	0.447	44,364
0.5-0.6	13.4	9.9	120.2	89.4	5.0	0.0	1.2	0.8	1.1	0.5	2.8	0.5	3.4	1.1	4.0	0.0	137.6	4.7	44.7	1.6	0.2102	0.552	26,053
0.6-0.7	14.1	9.9	102.5	83.4	5.0	0.1	1.1	0.7	1.1	0.4	2.8	0.5	3.2	1.2	4.0	0.1	142.5	4.3	43.8	3.3	0.6126	0.649	32,544
0.7-0.8	10.2	10.8	109.5	129.0	4.9	0.2	1.1	0.6	1.1	0.4	2.5	0.5	3.2	1.1	3.9	0.2	141.2	4.9	39.6	5.9	1.0557	0.742	30,345
0.8-0.9	15.0	10.1	108.7	85.5	5.0	0.1	1.1	0.6	1.1	0.5	2.8	0.4	3.0	1.3	4.0	0.1	139.2	4.9	33.7	2.0	1.7513	0.852	23,338
0.9-1.0	11.8	9.1	79.6	62.0	5.0	0.0	1.1	0.6	1.0	0.3	2.9	0.3	3.2	1.1	4.0	0.0	141.5	4.8	30.6	3.2	2.4372	0.920	13,581

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

SMR cumulative rainfall intensity 3 days , 100 year return period

	Parameter																						
Probability	1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	20.2	9.7	178.7	120.2	4.5	0.5	1.2	0.8	1.2	0.7	2.5	0.6	3.4	1.2	3.5	0.5	385.6	45.9	54.1	6.2	-2.4174	0.082	46,982
0.1-0.2	10.0	10.0	83.1	78.7	4.4	0.5	1.1	0.6	1.0	0.3	2.2	0.7	3.3	1.2	3.4	0.5	405.7	41.4	52.1	5.5	-1.6939	0.155	100,560
0.2-0.3	7.1	9.9	61.3	92.9	4.6	0.5	1.1	0.6	1.1	0.4	2.4	0.7	2.7	1.3	3.6	0.5	354.0	58.7	51.3	6.4	-1.0016	0.269	52,601
0.3-0.4	15.3	12.6	167.7	135.7	4.9	0.3	1.1	0.6	1.1	0.6	2.6	0.5	3.0	1.2	3.9	0.3	399.8	53.6	47.2	5.3	-0.479	0.382	39,551
0.4-0.5	18.6	8.9	179.4	86.5	5.0	0.1	1.1	0.7	1.1	0.6	2.9	0.4	2.8	1.4	4.0	0.1	412.2	60.5	44.7	1.3	-0.05	0.488	44,378
0.5-0.6	14.3	9.0	123.2	76.2	5.0	0.1	1.1	0.6	1.1	0.5	2.8	0.5	3.0	1.4	4.0	0.1	382.0	64.0	44.6	1.3	0.3263	0.581	47,606
0.6-0.7	9.9	9.2	79.8	84.5	5.0	0.1	1.1	0.5	1.0	0.4	2.6	0.6	3.1	1.3	4.0	0.1	365.8	55.8	43.9	2.9	0.7231	0.673	38,381
0.7-0.8	9.2	10.5	95.9	116.5	5.0	0.2	1.1	0.6	1.0	0.3	2.5	0.6	3.3	1.1	4.0	0.2	340.7	36.3	40.5	5.3	1.1828	0.765	32,263
0.8-0.9	15.4	9.5	102.7	75.4	4.9	0.3	1.1	0.6	1.1	0.5	2.8	0.4	3.0	1.3	3.9	0.3	357.6	38.3	33.0	2.6	1.8923	0.869	23,405
0.9-1.0	8.5	8.7	65.3	62.9	5.0	0.0	1.1	0.6	1.0	0.3	2.8	0.4	3.0	1.1	4.0	0.0	355.8	32.9	30.8	3.4	2.6471	0.934	13,503

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

CONCLUSIONS

Followings are conclusions on the research:

1. This study determines the sensitive areas of landslide and cut slope failure due to urban development in Phuket area. Weighting factor method was used through GIS application. Engineering soil properties were considered in weighting factor analyses and found to have great effect on landslide prediction. Furthermore, RMR and SMR were also considered in order to investigate the effect of rock mass quality and found to have effect to landslide prediction as well. However, verification needs to be done in the future.

2. The results of weighting factor method shows that RMR and SMR factors have slight effect on landslide hazard map.

3. Landslide potential classes done by cumulative frequency analysis gives more realistic result than using equal range of score concept.

4. RMR and SMR value show direct relation with the prediction of landslide for slope cutting.

5. As for rainfall intensity factor, the landslide potential map that considered 1 year return period of rainfall gives large difference compared to the map that used concept of 5 return periods of rainfall.

6. The cumulative frequency analysis of total score shows limited accuracy due to limited and slightly biased data.

7. RMR and SMR values have significant effect on landslide probability of failure when analyzed by logistic regression analysis.

8. Figure 91 and Figure 92 show the recommendation of landslide sensitive areas for cut slope by weighting factor method and logistic regression analysis respectively. The map is valid only for slope cutting that has angle of less than 1:1.2.

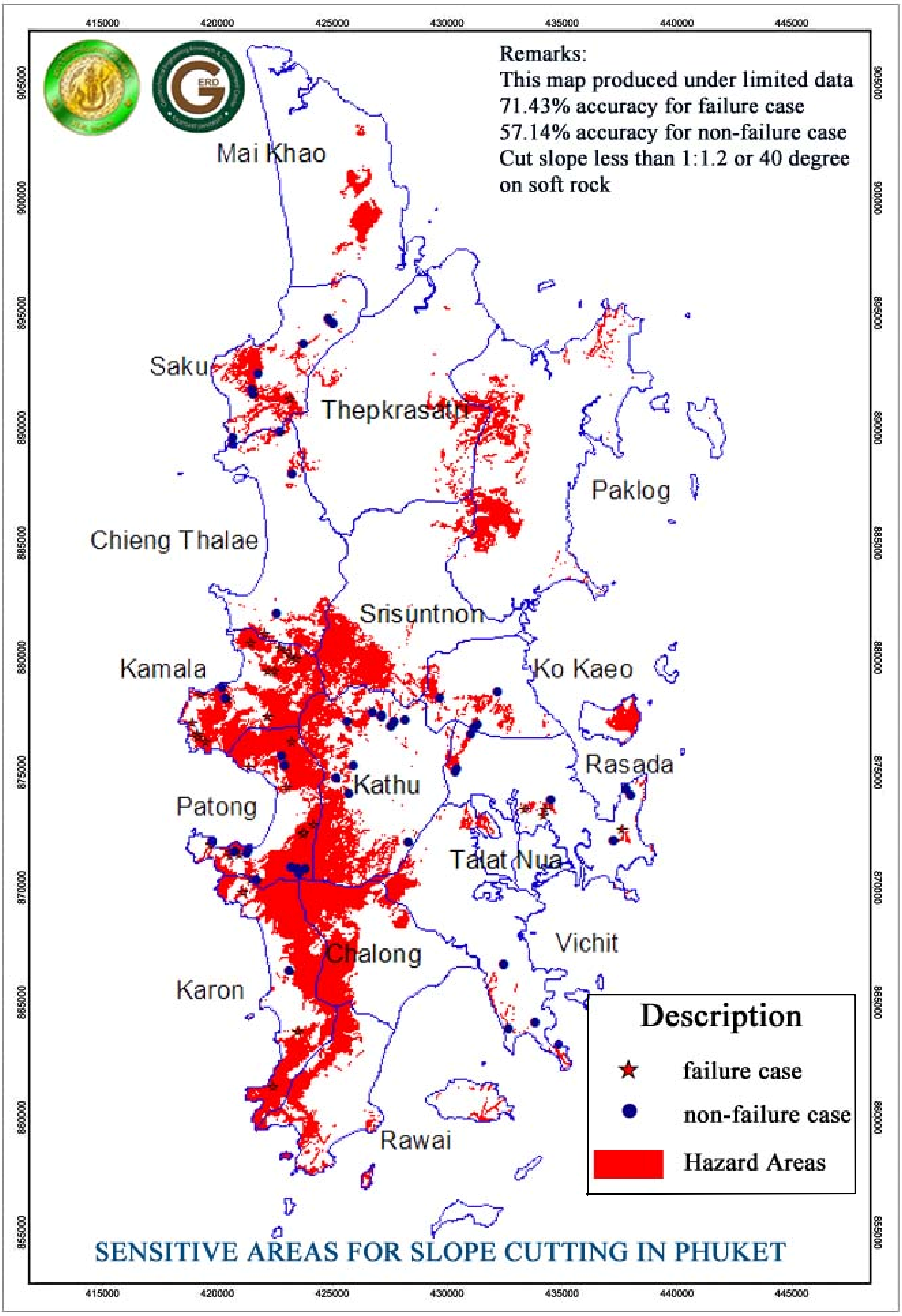


Figure 91 Recommendation of landslide sensitive area for cut slope by weighting factor analysis

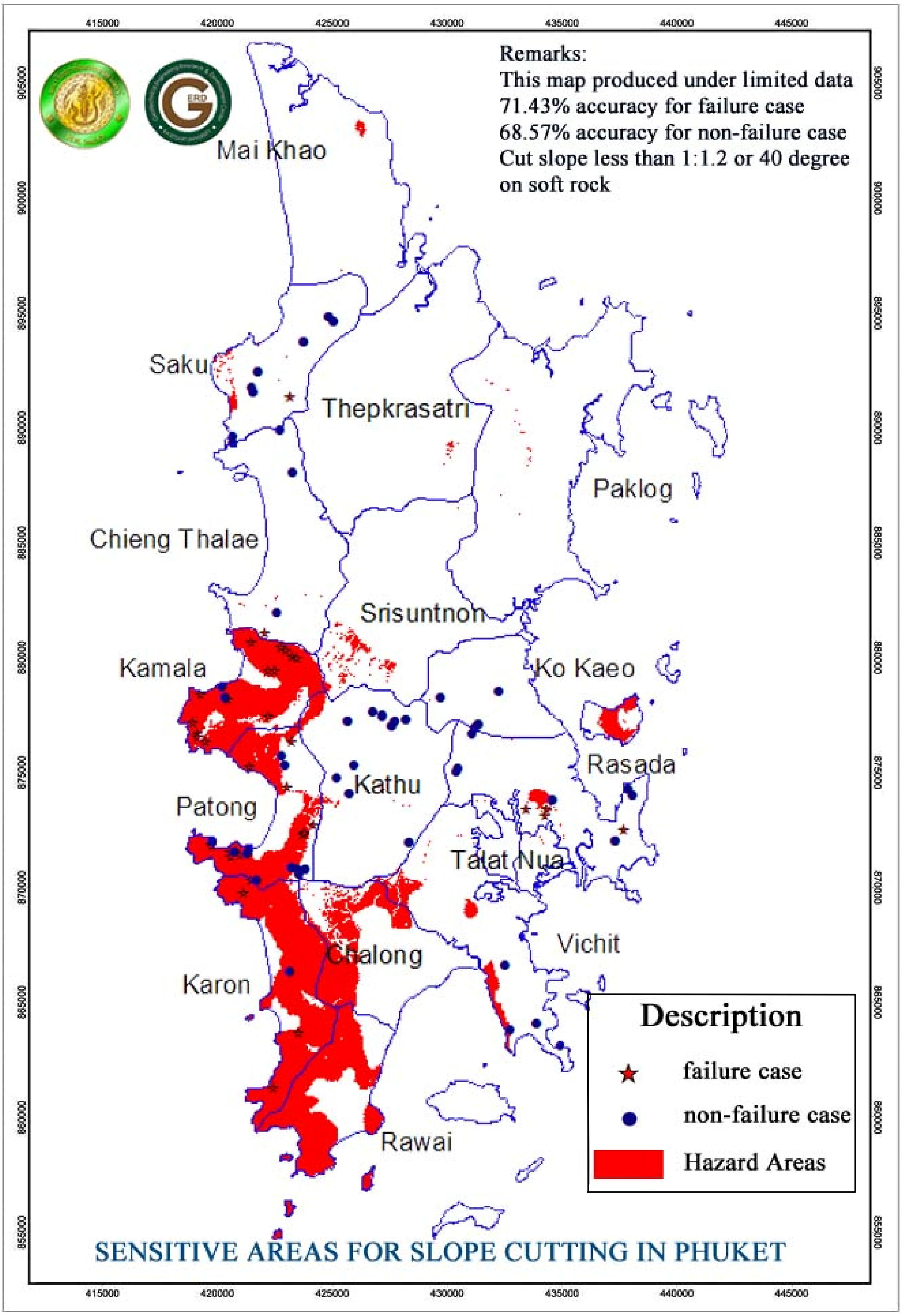


Figure 92 Recommendation of landslide sensitive areas for cut slope by logistic regression analysis

RECOMMENDATIONS

Recommendation for future research can be summarized as follows:

1. Watershed and accumulation of residual soil need to be included in the future analysis of landslide prediction.
2. The produced map shows only areas that can generate landslide hazard. Flow modeling needs to be done to predict affected areas.
3. Lesser biased SMR data and slope condition need to be added to improve accuracy of the analyses.

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